# AVOIDING COMMON ANESTHESIA ERRORS

2nd EDITION

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Wolters Kluwer

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Prepress Vendor: Aptara, Inc.

2nd edition



9 8 7 6 5 4 3 2 1

Printed in China

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978-1-4963-5518-8
Library of Congress Cataloging-in-Publication Data
available upon request

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To Charlie and Lisa Sandson, and Neil too, of course—this book would never have happened without your love and patience; many thanks also and always to the people who extended their unwavering support during the past few hectic years. **Catherine Marcucci, MD**

To my family, who continue to inspire, and all of the other individuals who have taught me, challenged me, and encouraged my lifetime of learning. **Brian T. Gierl, MD**

To Robin, my life-long source of inspiration; and to our granddaughters, Noa and Romi, my source of energy for the future. **Jeffrey R. Kirsch, MD**

The editors also wish to dedicate this book to the following individuals for their love and/or steadfast support:

**Ray Graber:** To my lovely wife, Mary; and our kids—Luke, Colin, and Aubrie

**Steve Orebaugh:** To my wife, Jennifer; and my daughter, Olivia

**Melissa George:** To my parents, Melanie and Joseph Smola; and my husband, Joe George

**Nick Nicholson:** To my wife, Jo Ann Nicholson

**Brian Mitchell:** To my wife, Katherine Mitchell

**Ryan Fink:** To Derek Applewhite, PhD for constant inspiration and support; and to Miko Enomoto, MD and Jeffrey Kirsch, MD for their mentorship and guidance

**Ryan Anderson:** To Lisa

**Matthias J. Merkel:** To my wife, Jennifer; and my daughters, Rebecca, Katharina, and Annika Merkel

**Rick Rosenquist:** To my wife, Ellen; and my children, Anders, Taryn, Leif, and Karl

**Kirk Lalwani:** To my wife, Seema Lalwani, who has dedicated her career to our family; and to my children, Nikita and Rohan, who inspire me to do the best I can

**Laurel Moore:** To Dr. Charles R. Moore, my father and favorite anesthesiologist

**Ed Avery:** To my wife, Lauren Avery; and our children, Sophia and Edwin Avery V

**Chris Swide:** To my wife, Sharon Kenny; and Joseph, Erin, and Thomas Swide

**Cobin Soelberg:** To my endlessly supportive parents, Doug and Cheri Soelberg; and my darling wife, Julie Soelberg

**Amr Abouleish:** To my wife, Lamia Elerian, MD, for her support and patience

# PREFACE

> "Good decisions come from experience, and experience comes from bad decisions."
>
> **—Mark Twain**

All medical providers are awash in information with more and more being published each week. The relevant publications are well summarized in a multitude of anesthesia textbooks to define the science of medicine. But what about the art of medicine? One could memorize Miller's Anesthesia without having any idea how to plan or execute an anesthetic. While checklists guide the response to an emergency, experience guides the seasoned practitioner away from that emergency. This book guides the reader through means to identify potential problems, develop plans to avoid those problems, and to treat those problems to minimize their impact on the patient's recovery.

Many texts have been published that describe errors by extrapolating scientific studies and adding expert opinion. Those texts often neglect to spell out a plan. The Avoiding Common Errors series provides plans for avoiding and treating situations and communicates those plans in an informal and often humorous manner. As Mark Twain is quoted above, there is a lot to be learned from bad decisions. However, there is no reason to make all those bad decisions yourself! Reading about the risks and pitfalls of various strategies is a good way to avoid complications.

The first edition of this book reviewed 215 situations in which common errors might occur as an effort to convey highlights from the published literature and expert opinions based upon the experiences of over 300 authors. It was very popular here in the United States and was also published in six foreign language editions. This second edition describes the cause, diagnosis, and treatment of a total of 305 situations. The text reflects on the conversations that occur between a seasoned attending anesthesiologist and a trainee before a case. Like those conversations, most chapters can be reviewed in 10 minutes or less. The situations can be used to spur conversations with trainees as well. Although some of these situations are infrequent, they are very relevant when they do present. Each patient is rightfully only concerned with their own situation and most patients fully expect to awaken perfectly well after their procedure, regardless of their preoperative status or the complexity of the procedure. Hospital administrators tend to agree with them. This text provides strategies to optimize the risks and benefits of anesthesia for your patients … and keep you off the podium at the Morbidity and

Mortality conference, and maybe even out of the courtroom.

In reviewing, revising, and developing new content, we once again owe a tremendous debt to our contributing authors and section editors. Everybody who contributed to the book enthusiastically gave us their interest, time, and expertise. We literally could not have put Avoiding Common Anesthesia Errors, Second Edition together without them. Our section editors were just astounding in their dedication to the project and we are grateful for their patience and commitment.

We would also like to give additional special mention to several individuals. These are the individuals who took topics and subjects on a moment's notice and developed them with expertise, commitment, and good humor. First and foremost, we thank Raymond G. Graber, MD for joining us as Associate Editor-at-Large while the manuscript was "in preparation" and researching, reviewing, and writing up a number of important topics, with the quickest possible turnaround. We also thank Brandon Togioka, MD, Juraj Sprung, MD PhD, Toby Weingarten, MD, Erica Wittwer, MD PhD, Edwin G. Avery IV, MD, and the perioperative nursing staff at the University of Pittsburgh Medical Center for being terrific "go-to" people whenever we were stalled on a topic.

We would also like to note the students and medical and legal professionals who took time away from their own educational programs, specialties, and busy clinical practices to contribute to ours with their ideas and expertise: Melissa R. George, DO, Matthew DeCaro, MD, F. Jacob Seagull, PhD, Albert Liao, LAc, Kristin King Liao, LAc, Scott Mist, PhD MAcOM LAc, Maria Lanzi, MS MPH ANP-BC COHN-s CTH, Sarah Foster-Chang, DNP APRN-BC COHN-s, Benjamin Conner, MSc MD/PhD3, Elizabeth Herzog, MD, Laura A. Donegan, MD, Carol F. Bodenheimer, MD, Daniel L. Glennon, JD MA, Renee A. Metal Esquire, Sara Lyons, MSN RN CNOR, Charles H. Sandson, BS IME'21, Lisa L. Sandson BArch'24, and Neil B. Sandson, MD. And thanks again as ever to the great Theresa Hanson at the Mayo Clinic!

This book has its own dedicated section pertaining to perioperative drug--drug interactions (DDIs), naturally. In putting this material together, we once again reviewed just about every published paper of Evan Kharasch, MD PhD. And so we thank him, as before, for his pioneering research in the field of DDIs and the cytochrome P450 enzyme system—it continues to motivate and inform our educational efforts in this important and relevant area of clinical perioperative practice.

We extend our gratitude to a number of senior physicians for their unique contributions: John L. Cameron, MD at Johns Hopkins for renewing his permission for us to quote him, Robert Gaiser, MD at the University of Kentucky for writing our foreword, David Zvara, MD FAHA for writing our concluding chapter, Peter Biro, MD for helping us with his unique expertise, Randal O. Dull, MD PhD for developing

content on the cytochrome P450 enzymes that we refer to constantly, Lorrie A. Lee, MD and Karen Domino, MD MPH for their expertise on the Anesthesia Closed Claims Project, Amr Abouleish, MD and Norman A. Cohen, MD for their contributions to the always important subject of professional practice, Poune Saberi, MD MPH for introducing us to our Occupational Health clinicians and authors, Jeffrey A. Grass, MD for reviewing chapters, and surgeons Mark K. Wax, MD FACS, Michael J. Moritz, MD FACS, Keith A. Chadwick, MD, Soon Park, MD, and Steven J. Busuttil, MD for their collective clinical expertise. We also extend our heartfelt thanks to John Kelly, MD, Chief of Staff of the Corporal Michael J. Crescenz Philadelphia VA Medical Center, for his commitment to the project and sponsorship of the time required to complete it.

The editorial and development staff at Lippincott Williams & Wilkins Wolters Kluwer Health was once again great to work with and we must especially recognize David Murphy for his expertise, dedication, and patience. Dave was tops, by us, all the way through the project. We also send our gratitutde and compliments to Anamika Singh for her painstaking work in putting the book together and building the manuscript for us. This was a large and long project, with hundreds of contributors and thousands of chapter drafts, but we got it done with the steadfast support of the LWWWK Health folks who walked patiently beside us every step of the way.

And to close, we must once again acknowledge our authors and editors—this time for their outstanding generosity. Incredibly, every person who contributed to this book once again concurred that all royalties from this project remain pledged in perpetuity to the Foundation for Anesthesia Education and Research. We are humbled and honored to be associated with this wonderful group of dedicated and caring providers!

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# FOREWORD

It was Einstein who said, “Anyone who has never made a mistake has never tried anything new.” Any person, regardless of their level of experience, is at risk for error if approaching something new. No one wants to make a mistake and we do everything in our power to avoid it. As physicians, we are more in tune to mistake prevention because of the consequences of our mistakes. Any error may have a significant impact on the patient or their well-being. The best means to prevent an error is to practice the motto from the Boy Scouts, “Be prepared.” We become prepared by educating ourselves and by ensuring that all necessary equipment and personnel are available.

What is the best means to educate ourselves? This book, Avoiding Common Anesthesia Errors, is a step in the right direction. With the information readily available and referenced, the book provides the knowledge to prevent common mistakes in anesthesiology. It is intended for the students in anesthesia, both medical students and residents. It allows them to enter a new situation informed and prepared. However, it would be a disservice to state that the book is only for the novice. As I advance in my years, some things which were previously old are now new as I am asked to perform an anesthetic or a technique that I haven’t done in several years. Furthermore, as the specialty advances, previously learned information and techniques no longer apply and new information must be learned. The book encompasses the entire range of patients from the pediatric to the geriatric, addressing the skills such as airway management, invasive monitoring, and regional anesthesia to name a few. This book is clearly one that should be readily available to both the trainee who is in the midst of medical school or residency and the expert who discovers their area of expertise is too narrow for the current practice in Anesthesiology. To err is human, to own and to read this book, sublime.

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# ACKNOWLEDGMENTS

The editors would like to acknowledge the following authors who contributed chapters for the previous edition for providing a strong foundation for us to build on as we developed the content for this new second edition:

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# VENTILATION AND AIRWAY

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# Introduction

Steven L. Orebaugh, MD

Airway management is the centerpiece of anesthesia care. No other intervention is as emblematic of what we do to preserve patient safety as securing an airway and ensuring sufficient oxygenation and ventilation. Indeed, it can be considered a vital contract between anesthesiologists and their patients that this aspect of care will be competently provided. Whether for the induction of anesthesia, or during a resuscitation, most practitioners regard the establishment of an airway as the foundation of further management. Until this is accomplished, everything else seems to hang in the balance. When placement of an airway goes well, we on the anesthesia side may not attract much notice; however, when it does not proceed as planned, we develop a very high profile, very quickly.

Beyond the obligation to patient safety, and the demonstration of professional competence, there looms the specter of medicolegal liability. Failure to secure the airway carries important physiologic consequences that may lead to severe morbidity and mortality in a very short time. The clear connection, in such a case, between failure to provide the expected intervention, and the consequences resulting from hypoxia and/or hypercarbia, makes for a very difficult defense if a claim is made against the provider. Indeed, failure to adequately secure the airway is a perennial source of medicolegal consequences in our profession, as evidence in both the American Society of Anesthesiologists (ASA) closed claims database and the UK airway registry. High-profile cases of failed airway management featured in the lay press presuppose that the anesthesiologist failed to do his or her job, as we have seen quite recently. Some anesthesiologists' careers have been challenged by such occurrences.

Hence, recommendations to optimize airway management can be of benefit to all acute care providers. What follows is a selection of short articles to help ensure optimal decision making in this often difficult setting, when management must be instituted with immediacy, and risks to patient safety are considerable. These articles include discussion of the ASA airway management algorithm, tips for difficult situations, and descriptions of various airway management techniques, reflecting the knowledge and personal experience of highly qualified practitioners.

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# Basics of Airway Management (Part I)—Always Keep in Mind Complications That Can Occur With Existing Endotracheal Tubes and Tracheal Extubation

Toby N. Weingarten, MD, Adam D. Niesen, MD, and Juraj Sprung, MD PhD

Anesthesia providers are specialists in establishing controlled airways for surgical procedures and mechanical ventilation. However, it is also essential that anesthesia providers be able to quickly diagnose and manage airway emergencies that can occur intraoperatively or in the intensive care unit, and during extubation.

## Inability to Ventilate due to Endotracheal Tube Occlusion

One of the most common airway emergencies is failure to ventilate a patient because of obstruction of an endotracheal tube (ETT). The lumen of the ETT typically becomes occluded from secretions or blood. ETT cuffs have been reported to cause obstruction secondary to overinflation and subsequent herniation into the distal aperture and/or Murphy eye of the ETT. Rarely, other objects, such as a dislodged nasal turbinate during traumatic nasotracheal intubation, can lead to occlusion. Tracheal pathology, such as tumors, can also occlude the ETT by covering the opening aperture(s) of the tube. The patency of an occluded ETT can be quickly confirmed, and in some circumstances cleared, by passage of a suction catheter. Irrigation with 5 to 10 mL of normal saline solution may be required to moisten dried secretions to make them amenable to suction. Occasionally, fiber-optic examination can be used to help establish the diagnosis, clear the obstruction, or guide repositioning of the ETT. In extreme circumstances, the ETT may need to be withdrawn and exchanged for a nonoccluded tube.

The ETT can also become occluded from external compression, such as clenched teeth in the nonparalyzed patient who becomes “light” during anesthesia. This situation can be avoided by inserting orally a “bite block” or an oral airway. The use of a “soft” bite block, such as a roll of taped gauze, may be less likely to traumatize oral structures than rigid plastic oral airways. Another common cause of external compression of the ETT is kinking of the ETT. This typically occurs when surgical personnel inadvertently apply pressure (lean) on the patient’s face. Typically, relieving the external compression will allow the ETT to straighten and reestablish patency. However, an ETT enforced with metal (wire spiral or metal-jacketed laser ETTs) can permanently

kink or deform from extrinsic pressure and may need emergent exchange. Also some laser ETTs are prone to fracture and require emergent exchange.

## Avoiding Unexpected Loss of the Airway in Already Intubated Patients

Inadvertent extubation during surgery or mechanical ventilation represents a life-threatening emergency. In order to avoid these situations, the ETT should be securely taped (adhesive tape), tied, or fixated with commercial ETT holders to avoid inadvertent dislodgement. In cases when the facial field is shared with the surgeon (e.g., oral procedures), additional ETT security may be achieved by pretreating the skin with liquid medical adhesives, such as benzoin, which increase surface stickiness. This may be important in a patient who presents for surgery unshaved. As a part of routine anesthetic management, ETT position (depth of insertion in regard to incisors) should be checked intermittently throughout the operation.

One of the greatest risks of accidental tracheal extubation is during change of patient position or patient transfer. Before patient movement, the ETT should be inspected to ensure it is firmly secured. Further, manually guarding the ETT by holding it adds another layer of safety. Prior to any patient movement the anesthesia provider should give verbal confirmation that he/she is prepared. During movement, an anesthesia circuit can get caught on a piece of equipment and pull out an ETT. Therefore, when possible, the ETT should be disconnected from the anesthesia circuit prior to repositioning or moving the patient. The rare exceptions are high-risk patients who **cannot tolerate uninterrupted oxygenation, and for those in whom oxygenation is dependent** on high levels of positive end-expiratory pressures (PEEP). The same caution with ETT should be exercised when turning the operating room table.

Caution is warranted in intubated patients during procedures of the head and neck, especially of the airway, and during endoscopic or esophageal procedures. Meticulous attention to securing the airway is mandatory. Manipulation of a gastroscope or transesophageal echocardiography probe can dislodge an ETT, and manually guarding the ETT may be recommended.

**Changes of body position also pose a risk of tube dislodgement. The Trendelenburg position can result in advancement of the ETT (up to 2 cm), and turning the head sidewise may result in similar ETT withdrawal (1.5 to 2 cm).** In patients whose ETT was originally inserted close to the carina or just below the glottic opening, these maneuvers can result in mainstem intubation or tracheal extubation, respectively. Therefore, assuring proper ETT placement to approximately mid-trachea will assure these mishaps. Typically in adults, the ETT should be placed between 20 and 23 cm at the incisors, depending on the patient's build and height. When placing

ETTs with a pre-existing bend, that is, down RAE ETTs, it is important that the bend be in the proper location to allow for optimal depth of the ETT. Downsizing a down RAE ETTs to a smaller internal diameter may not be feasible because of the location of the bend.

## Anticipate Potential Difficulties and Be Prepared to Treat Airway Failure After Extubation

Typical complications of premature tracheal extubation are hypoventilation, apnea, or obstructive breathing. Immediate postoperative apnea or hypoventilation is most often caused by residual anesthetic and opioid effects, incomplete reversal of neuromuscular blockade, or the excessive relaxation of oral tissues causing obstructive breathing. Some patients may have increased sensitivity to anesthetic agents (e.g., elderly, children, patients with obstructive sleep apnea), which can contribute to hypoventilation. Therefore, patients need to achieve extubation criteria before being extubated (Table 2.1). Specifically, before tracheal extubation, the risk of apnea or hypopnea can be minimized by achieving adequate spontaneous breathing. In addition, anesthetic levels should be low enough to ensure that the patient is able to follow simple commands as well as demonstrate adequate return of muscle strength (e.g., squeezing hands, head lift sustained >5 seconds). The neuromuscular reversal agents should be administered well before the end of the surgery to allow enough time for maximal inhibition of pseudocholinesterase (typically 5 to 15 minutes, depending on the reversal agent used). Patients who have received nondepolarizing muscle relaxants should receive reversal agents, even if the train-of-four ratio appears visually normal, since it has been shown that estimation of this ratio by eye is often inaccurate. Exception to that practice should be rare and well considered.

**Table 2.1 ■ General Criteria for Tracheal Extubation**

| Vital Function | Parameter |
|---|---|
| Hemodynamics | Stable blood pressure<br>Stable heart rate |
| Metabolic | Body temperature at acceptable normothermic range |
| Respiratory drive | Respiratory rate >8 per min |
| Respiratory muscle strength | Tidal volume >5 mL/kg IBW<br>Vital capacity >15 mL/kg IBW |

| | |
|---|---|
| | Negative inspiratory pressure >−20 cm $H_2O$ |
| Oxygenation/ventilation (on room air or $O_2$ <40%) | $PaO_2$ >60 mm Hg<br>$PaCO_2$ <50 mm Hg |
| Muscle strength recovery | Strong handgrip, sustained head lift, and strong and purposeful extremity movements |
| Protective reflexes | Present gag, swallow and/or cough reflexes |

IBW, ideal body weight; $PaCO_2$, partial pressure of carbon dioxide in the blood; $PaO_2$, partial pressure of oxygen in the blood.

Another cause of a lost airway after tracheal extubation is laryngospasm. The highest risk of laryngospasm occurs upon emergence from general anesthesia after tracheal extubation; however, it can occur at any stage while using the laryngeal mask airway (LMA). Certain patients are at higher risk, including children and those with a history of smoking, asthma, bronchitis, or bronchiectasis. In addition, among inhalational anesthetic agents, desflurane is more likely associated with laryngospasm. If the use of bag-mask positive-pressure ventilation with 100% oxygen is unsuccessful in breaking the laryngospasm, administration of an intravenous induction agent and/or succinylcholine may be indicated.

Special caution should be exercised before tracheal extubation in a patient whose mouth has been wired shut after orthognathic (jaw) surgery. For these patients, a wire cutter must be readily available at the bedside at all times to facilitate access to the oropharynx in case of emergency. To avoid a potential airway emergency, these patients should be fully awake and responding appropriately to commands before tracheal extubation. All preventive measures should be taken to decrease the postoperative nausea and vomiting, including placing a nasogastric tube and suctioning of gastric contents, administering antiemetic agents, and intraoperative use of a total intravenous anesthetic technique. Rubber bands are nowadays more frequently used for jaw immobilization in lieu of wires to keep the mouth closed and are more easily removed to facilitate airway access in emergent situations.

## Preparing for Safe Tracheal Extubation

Even though the majority of tracheal extubations are routine, the anesthesiologist must always be prepared for acute decompensation and extubation failure. Fortunately, many patients at risk may be identified (history of a difficult airway, facial deformities, presence of oral or laryngeal pathology, etc.). However, even in straightforward

patients, the anesthesiologist should always have a backup plan at the time of tracheal extubation. Necessities that always must be available include:

) 100% oxygen source and face mask with bag-mask device
) Oral and tracheal suction system
) Laryngoscope with various blades, videolaryngoscope, ETT, intubating stylet, and alternative supraglottic devices (LMA)
) Oral and/or nasopharyngeal airway
) Induction drugs drawn up and ready, especially propofol and succinylcholine

Postextubation apnea or hypopnea should always be anticipated. It can generally be managed with positive-pressure bag-mask ventilation, which may be aided with the placement of an oral or nasopharyngeal airway. However, if ventilation is not achieved, airway patency must be reestablished by reintubation or placement of an alternative airway device, such as an LMA or other supraglottic airway devices. Also the use of noninvasive ventilation with CPAP and BiPAP may ameliorate transient postoperative hypoventilation or obstructive breathing and avoid reintubation.

## Avoiding Complications of Premature Extubation

Postextubation airway complications may be prevented by proper timing of extubation, preparation for urgent or emergent tracheal reintubation, and adequate level of postextubation monitoring and care. Figure 2.1 summarizes guidelines for the management of tracheal extubation for patients at risk for extubation failure. Typically, high-risk patients are allowed to awaken fully prior to removal of the ETT. Because intubated and awake patients may cough or gag, a deep extubation may be desired when the integrity of the surgical repair may be compromised by patient straining. However, this option may not be safe in a high-risk patient. In this special circumstance, the use of the "remifentanil technique" as a cough suppressant may be employed for extubation. With this technique, a remifentanil infusion is initiated at the end of the case (or continued from the case) while the anesthetic agent is discontinued and the muscle paralysis reversed. Remifentanil is then titrated to allow for spontaneous respirations. Extubation occurs once the patient is fully awake and spontaneously breathing.

Another special circumstance is when a high-risk patient may have airway compromise following extubation. An example is a patient who undergoes a cervical spine fusion and now has a forward flexed head position. In such situations, an airway exchange catheter (AEC) can be useful in postoperative airway management (Fig. 2.2). Once the patient meets extubation criteria, the AEC is placed inside the lumen of the ETT and the ETT is removed. Instillation of 3 to 4 mL of 4% lidocaine through the ETT, before AEC is placed, greatly improves catheter tolerance. In case of extubation failure, the AEC can be used as a means of (temporary) oxygenation, or jet ventilation, and can

also serve as a conduit for tracheal reintubation if needed. Special adaptors (a Luer-Lok adaptor for jet ventilation and a 25-mm adaptor for positive-pressure ventilation) that fit to the proximal part of the AEC are provided with standard AEC kits.

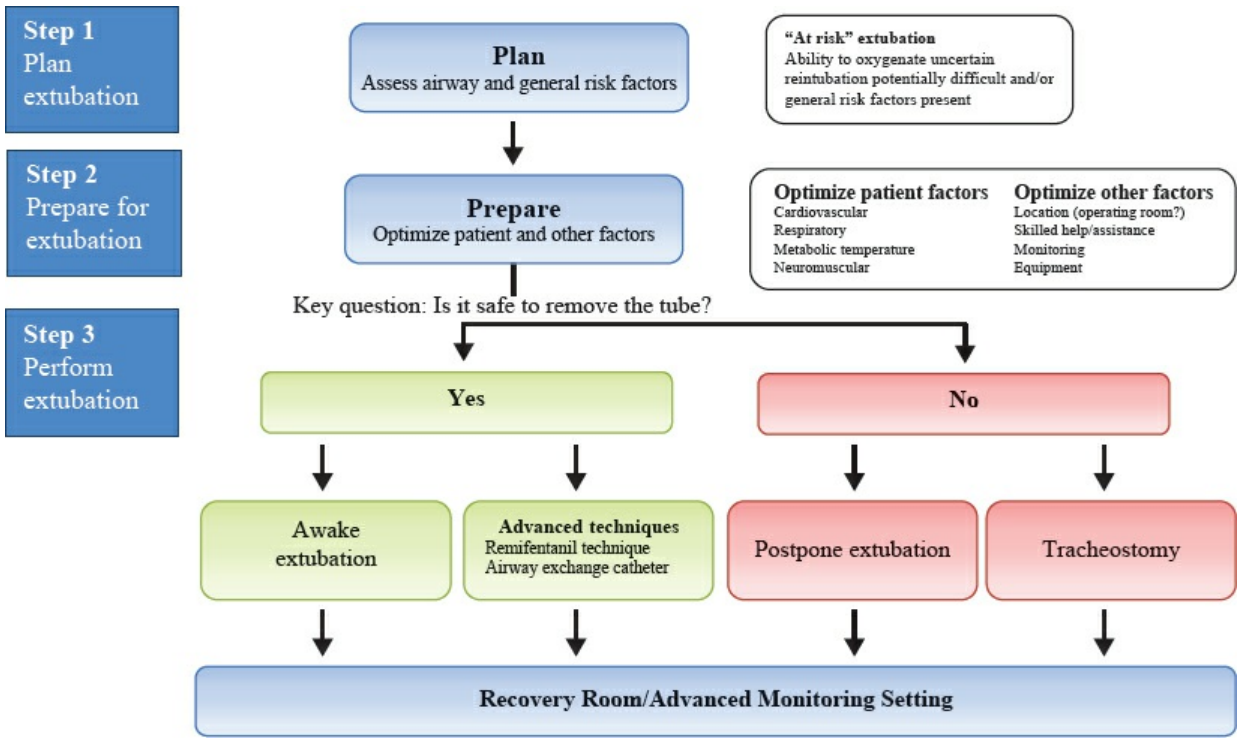


**Figure 2.1.** Difficult airway extubation guidelines. (From Popat M, Mitchell V, Dravid R, et al. Difficult Airway Society guidelines for the management of tracheal extubation. Anaesthesia. 2012;67(3):318–340. Copyright © 2012 The Association of Anaesthetists of Great Britain and Ireland. Reprinted by permission of John Wiley & Sons, Inc.)

However, AECs are associated with risks such as lung perforation (pneumothorax), misplacement in the esophagus, or barotrauma (with jet ventilation). The use of video-assisted laryngoscopy has been suggested to improve visibility of the periglottic structures and facilitate advancement of the ETT into the trachea. In order to prevent lung injury, the AEC should be inserted equal to the typical depth of the tip of the ETT, and not more than 25 cm orally or 27 to 30 cm nasally. The tip of the AEC should always be above the carina. When the AEC is contemplated to be left in place for some (limited) time, as a "prophylactic" conduit for reintubation, the use of 3 to 4 mL of 4% lidocaine down the pre-existing ETT (before extubation) will aid patient comfort in tolerating temporary placement of the AEC.

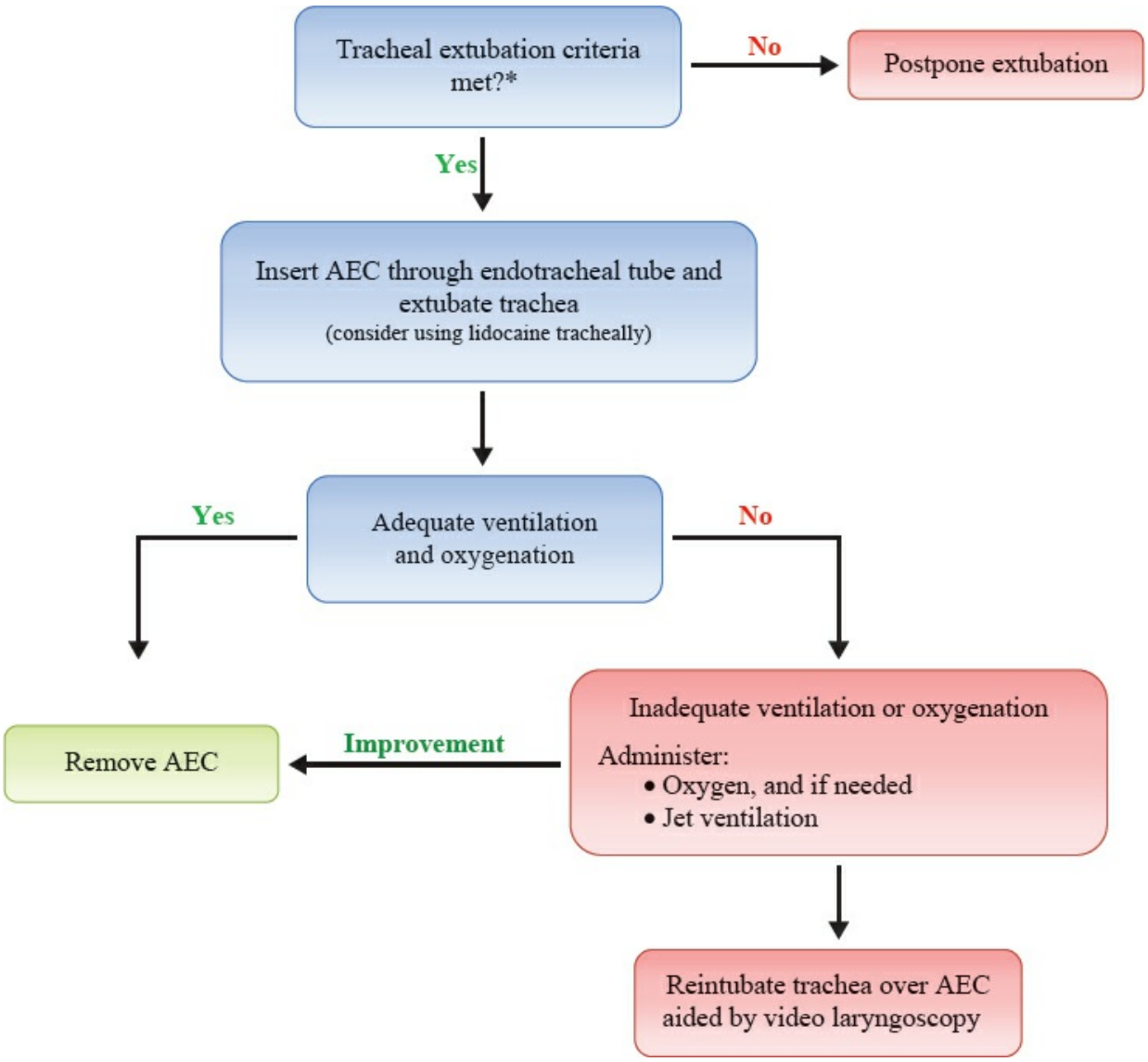


**Figure 2.2.** Steps for tracheal extubation over airway exchange catheter (AEC) in patients with high-risk "difficult airway" (see Table 2.1). (From Popat M, Mitchell V, Dravid R, et al; Difficult Airway Society Extubation Guidelines Group. Difficult Airway Society guidelines for the management of tracheal extubation. Anaesthesia. 2012;67(3):318–340.)

## Exchanging a Double-Lumen ETT With a Single-Lumen ETT

Special caution must be exercised when a double-lumen ETT is changed to a single-lumen tube, especially in patients known to have a difficult airway. For some patients it may be even safer to keep the double-lumen ETT in place. In these circumstances, the anesthesiologist deflates both the bronchial and tracheal cuffs and then withdraws the bronchial (distal) lumen into the mid-trachea. After repositioning, only the tracheal cuff should be reinflated. Proper position may be confirmed with fiber-optic bronchoscopy. Another approach is to use a single-lumen ETT from the beginning of the case (or maintain it in those who are already intubated) and use a bronchial blocker to perform one-lung ventilation. A double-lumen ETT can be exchanged using AECs; however,

their use does not guarantee success and a backup plan is required. To increase reintubation success, the entire process should be monitored with videolaryngoscopy.

## TAKE HOME POINTS

- Failure to ventilate can be related to occlusion of the ETT, either from intrinsic blockade (plug) or extrinsic force (kinking).
- Care must be taken to avoid inadvertent extubation during movement or repositioning of patients, head and neck surgeries, and endoscopies.
- Lack of airway preparedness can have disastrous consequences when planning extubation of the patient. A strategy to minimize postextubation airway complications must include careful timing for tracheal extubation and assessment of conditions that can lead to airway incompetence.
- The most frequent complications of premature tracheal extubation are hypoventilation, apnea, or obstructive breathing. Immediate postoperative apnea or hypoventilation is most often caused by residual anesthetics and opioids, incomplete reversal of neuromuscular blockade, or the presence of redundant oral tissues.
- Maintain vigilance for laryngospasm. Be ready to move quickly to positive-pressure ventilation with a mask, or if that fails, induction agents and/or succinylcholine.
- Do not extubate trachea without being prepared to effectively reintubate if necessary.

## Suggested Readings


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3

# Basics of Airway Management—Part II (More Tips and Tidbits to Read on the Train)

Richard Wick, MD, Catherine Marcucci, MD, and Steven L. Orebaugh, MD

As described more formally in the preceding chapter, airway management is both a science and an art. Every anesthesiologist must think about airway management on a constant and ongoing basis and commit to lifelong study of this most crucial art of our clinical practice. **And we urge each clinician to establish the goal of getting through his or her entire clinical career without losing a single airway!** It is also important to be aware of and minimize complications even when the airway was apparently easy to establish and maintain.

- The American Society of Anesthesiologists regularly updates the Difficult Airway Algorithm. The latest update was in 2013. Know this document!
- Be aware that many of the advances in airway management have come in the form of intubation adjuncts or equipment. For example, the Difficult Airway Algorithm now includes video-assisted laryngoscopy as an initial approach in limited airways and as a useful backup modality when unexpected difficulties arise.
- Try to become an expert in each new airway device and technique as it is developed and applied clinically, but remember that the most valuable airway techniques are sometimes the simplest and most basic—a nasal trumpet, a headstrap, or even a jaw thrust. It is best to become proficient with a new airway device on patients with a normal airway in a controlled OR setting before trying to use the new airway device on a complicated patient or in an emergency situation.
- Control your airway situation by controlling your airway drugs—do not get lulled into a false sense of security because you have used propofol, succinylcholine, and the other standard induction and paralytic agents thousands of times. These are not new drugs, but new clinical issues and complications arising from their use are still constantly being reported in the current literature. Spend some time reviewing the new literature on old drugs. Better yet, make a habit of scanning each journal in your inbox FIRST for any article or report that pertains to an airway issue.
- Don’t keep giving induction agents and paralytics if you really are in airway trouble, unless you have significant laryngospasm requiring succinylcholine.
- Side effects from induction medications or paralytic agents such as hypotension or bradycardia can at times seem to overshadow acute airway management. Remember that these are “second-tier” issues in an airway emergency and often easily treated once the airway is properly secured. Likewise, hypoxemia and hypercarbia can only exacerbate these side effects so, again, control your clinical situation by controlling the airway.

- Also remember that one of the most valuable drugs in airway management is oxygen—a classic airway teaching maxim is "put the patient on oxygen first and then think."
- If airway difficulty is suspected, have the patient breathe 100% oxygen for 5 minutes, remembering that oxygen utilization by the (nonpregnant) human adult is approximately 3 mL/kg/min. If you have fully denitrogenated the lungs, the chances of having "the oxygen outlast the succinylcholine" are increased. But remember, classic studies have demonstrated that ill patients can have critical desaturations in under 5 minutes which is well before the 7 to 8 minutes that may be necessary to have a functional return of the spontaneously ventilating patient.
- When you are just learning airway skills, seek out mask cases. The successful mask airway is the foundation on which all airway management is based and is a skill best learned with repeated practice. Also, learning to efficiently and calmly use a bougie is a skill best learned in a controlled setting. Stepwise rehearsal of instructing an assistant unfamiliar with a bougie is important as well (locating the device, endotracheal tube (ETT) manipulation over the bougie, when to remove the bougie, etc.) so that in time-sensitive situations you have an articulate and efficient process.
- Do not underestimate the amount of airway edema and/or bleeding that can occur with even one or two attempts at laryngoscopy. This is especially important in obstetric and smoke-inhalation patients, who are already at risk given generalized edema throughout airway tissues. Moreover, the pediatric airway can change dramatically with each repeated laryngoscopy given its small size and numerous differences from the adult airway.
- Remember that for an intubated patient, the tip of the ETT follows the chin. Flexing the patient's head toward the chest seats the ETT more deeply in the trachea and vice versa. This is important to note both for initial ETT placement as well as troubleshooting ventilation issues after further patient positioning.
- Excessive tape on the ETT can be as troublesome as undertaping the device. Many senior anesthesia providers have anecdotes involving skin damage to patients' faces or accidentally extubating too soon when "trying to loosen the tape" in advance of being asked to do a planned extubation, such as in a tracheostomy.
- Assessing adequate muscle strength in the setting of neuromuscular blocking medications is a difficult task, and studies show that with current train-of-four technology we have very little sensitivity in definitively measuring this level of paralysis. It is best to use standardized methods to assess patient strength before progressing to extubation (e.g., head lift, leg lift) and avoiding assessments that only demonstrate the patient's ability to follow verbal commands (e.g., "squeeze my hand"). This question does little to highlight that the patient can perform meaningful tasks related to successful extubation. Better verbal cues are: "take a deep breath," "open your mouth," or "try to swallow" as these will increase your confidence that the patient will be able to take a deep enough breath to cough, open their mouth for

suction, and be able to control their secretions (particularly important in patients with myasthenia gravis, who may demonstrate bulbar weakness not predictable from the assessment of peripheral strength).

- In addition, the Yankauer suction tip is useful in assessing the readiness for extubation. Patients who do not respond to deep pharyngeal suctioning with a vigorous gag probably do not have adequate return of airway reflexes, and a bit more time should be allowed before removing the tube. Similarly, passage of a suction catheter down the ETT should elicit a strong cough response, for patients in whom return of reflexes or strength is in question.
- For patients who have been intubated for more than 6 hours, extubation should not occur until the patient demonstrates adequate strength, cognition, and a leak around a deflated ETT cuff. Failure to demonstrate a leak may result in a completely obstructed airway at the time of extubation.
- A surprising number of serious airway events include the fact that the ETT was actually in the trachea at some point and then was accidentally or purposely removed due to delayed taping, an attempt to change the ETT to a more advantageous size, or the like. A corollary to this is to never feel oversecure when using a tube changer to change the ETT even if the initial airway management was not especially difficult. Extubation of a critically ill patient could be disastrous as hemodynamics, pulmonary mechanics, and neurologic function can all be disrupted, reducing the time that they can tolerate any difficulty replacing an ETT. **Note that up to one-third of airway management complications occur at or shortly after extubation, as noted in 2011** in the Royal College of Anaesthetists Report. This risk is highest **outside** the OR, such as in the ICU or PACU. Such airway complications are attributable to failure to anticipate problems after the extubation, inadequate assessment of the potential for ventilation problems, and lack of a specific plan for reintubation.
- When called to a non-OR location (e.g., ICU, patient ward, emergency department) to do airway management, you, as the expert airway consultant, should expect to assume control of the airway and the attendant clinical decisions at the time of your arrival. Remember that you are not obligated to continue any inappropriate or ineffectual airway management that is underway if you do not feel it is appropriate. Ask for a brief summary of the pertinent patient history and recent airway and ventilation clinical status, including pulse oximetry readings and trends, ventilator settings, arterial blood gas values.
- Always be very vigilant when doing airway management in non-OR locations. It is so easy to forget the routine procedures or adjuncts readily that are available and practiced in the OR! So, develop your own mental checklist to insure that you have what you need to bring everybody through the urgent or emergent airway situation. The authors personally use the STOP-MAID mnemonic:

**S** • Suction

**T** • Tools for intubation (laryngoscope handle, straight and curved blades) and for difficult ventilation and/or intubation (LMA, intubating LMA, laryngeal tube airway, lightwand, optical stylet, videolaryngoscope, etc.)

**O** • Oxygen source (for preoxygenation and ongoing oxygenation between attempts)

**P** • Positioning (effective sniffing position, with ear canal level to sternal notch)

**M** • Monitors (EKG, pulse oxymetry, blood pressure, and end-tidal $CO_2$ or other $CO_2$ detection)

**A** • Ambu bag (with face mask); airway devices (ET tubes, oral and nasal pharyngeal tubes, stylets, gum-elastic bougie)

**I** • Intravenous access

**D** • Drugs for induction (hypnotic, muscle relaxant, any desired adjuncts such as opioids)

- Remember that the best intubating aid to take with you may be another experienced anesthesia provider.
- Always ensure that an assistant understands what cricoid pressure is, why it's done, and how it's done, even if you have to take a moment to instruct an assistant. Keep in mind that before your arrival to an airway situation, the patient may (likely) have been ventilated by a bag mask for a prolonged time causing insufflation of an already potential full stomach. In these cases, cricoid pressure (and suction capabilities) may steer a bad clinical situation away from a full-blown catastrophe with subsequent aspiration. Also, make certain supplemental oxygen sources are adequate to complete the airway management.
- One of the most dangerous requests is the call to the intensive care unit to "change the tube," either due to secretions or a ruptured ETT cuff. Exhaust all options before removing this ETT. Call for a bronchoscope to confirm that there truly are secretions in the ETT and that mainstem intubation is ruled out. Try a wet throat pack in the supraglottic area if a cuff leak is suspected as the cause of the inability to deliver an appropriate ventilator volume. Do a direct laryngoscopy with the tube in place to make sure that a "leaking ETT cuff" is not just a cuff that has herniated out from the trachea. If the pilot balloon is broken (but ETT cuff is still intact) you can temporize the situation by cutting the tube going to the pilot and attach a syringe for cuff inflation

with an appropriately sized needle (usually 21 gauge) inserted into the cut pilot balloon tube and a three-way stopcock. Be sure "excessive leak" around an ETT isn't due to the combination of the patient requiring high airway pressures (poor pulmonary compliance) and low cuff pressure. When those options are exhausted, call for a colleague.

- Always remember to wear your mask and eye protection when intubating in the intensive care units. This is commonly where anesthesia providers incur eye or mouth exposures to body fluids (including every one of the authors).
- Don't abandon airway equipment from the OR or the emergency airway cart in a remote location. Remember that somebody may need and be looking for that pediatric bronchoscope later that night or the next morning. Always follow your institution's policies and practices to get the equipment cleaned and back where it belongs.
- For patients who have been intubated for more than 6 hours, extubation should not occur until the patient demonstrates adequate strength, cognition, and a leak around a deflated ETT cuff. Failure to demonstrate a leak may result in a completely obstructed airway at the time of extubation.
- Remember that even in healthy patients with "normal" airways, postintubation sore throat remains a source of frustration and patient dissatisfaction. Some measures that can be used to reduce sore throat include the use of supraglottic airways (See Chapter 7); using ETT cuff volumes that are sufficient to produce a seal, but avoiding higher volumes (See Chapter 9); avoiding large ETTs, unless bronchoscopy is planned; and minimizing the number of attempts to instrument and/or secure the airway. To that end, all preparations should be made for direct laryngoscopy to be optimum on the first attempt: thus appropriate sniffing position, appropriate personnel and equipment available, and routine use of external laryngeal manipulation to optimize the view of the glottis.

## TAKE HOME POINTS

- Although the authors talk about airway management being an "art," it does not mean that there are not right and wrong ways of performing airway management. The American Society of Anesthesiologists has developed a difficult airway algorithm that has become a standard for anesthesia providers and was last updated in 2013.
- The best advice a new practitioner can receive is to always err on the side of caution and to have many possible options in their armamentarium of airway management techniques. As you develop more skills and confidence surrounding this topic, learn to trust the "sixth sense" you may feel when investigating a potential difficult airway. Do not let your ego get in the way of taking a step back, considering awake airway management, or waking a patient up if already under general

anesthesia. An alive, untraumatized patient with an elective case cancellation is far superior to one with morbidity or mortality surrounding airway management.

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4

# Optimize the Airway: Bag–Mask Ventilation

Steven L. Orebaugh, MD

Mask ventilation is a noninvasive means of providing ventilation and oxygenation in nonbreathing patients and permits ready assistance of ventilation in those who are ventilating spontaneously. The ability of a provider to ventilate with bag and mask is life-supporting or even life-saving when direct laryngoscopy is impossible. In some circumstances, brief support with bag–mask ventilation (BMV) may be all that is necessary to ensure adequate ventilation and oxygenation during brief unconsciousness, while a reversible condition is addressed (or a short procedure performed), after which the patient can resume spontaneous ventilation. BMV is typically applied after induction of anesthesia, in the fasting patient without concern for aspiration of gastric contents, in order to maintain oxygenation while awaiting onset of muscle relaxation and the initiation of direct laryngoscopy for intubation. However, face mask ventilation should be withheld in emergencies, for known full stomach, and for those with gastric or esophageal conditions which predispose to reflux or regurgitation. Clear face masks are virtually universal today in anesthesia and critical care, so that regurgitation or emesis can be immediately detected.

In order to provide effective BMV, a tight seal must be maintained between the mask and face. In addition, positioning can aid in ensuring a patent airway for ventilation, usually through use of the "triple airway maneuver," which involves chin lift, head extension, and mouth opening. Mask fit should be ensured by placing the mask down upon the bridge of the nose, then pulling the jaw up into the mask as it is lowered onto the face; the air cuff of the mask should be appropriately inflated if necessary, to facilitate the fit. Most practitioners in anesthesia elect to use the left hand to apply the mask, and the right hand to squeeze the bag, by convention and the usual placement of the anesthesia machine in relation to the head of the bed. During mask placement, the thumb and forefinger are used to encircle the top of the mask, near the orifice for attachment of the circuit, while the remaining digits are aligned along the bony mandible of the patient, pulling the jaw upward. Ideally, the small finger "hooks" behind the angle of the mandible, allowing for an effective jaw thrust in addition to the triple airway maneuver noted above. **It is imperative to avoid simply forcing the mask down onto**

**the face and jaw, causing recession of the mandible and obstruction to airflow, as well as keeping the fingers off of the soft tissue in the floor of the mouth, which may also predispose to obstruction.**

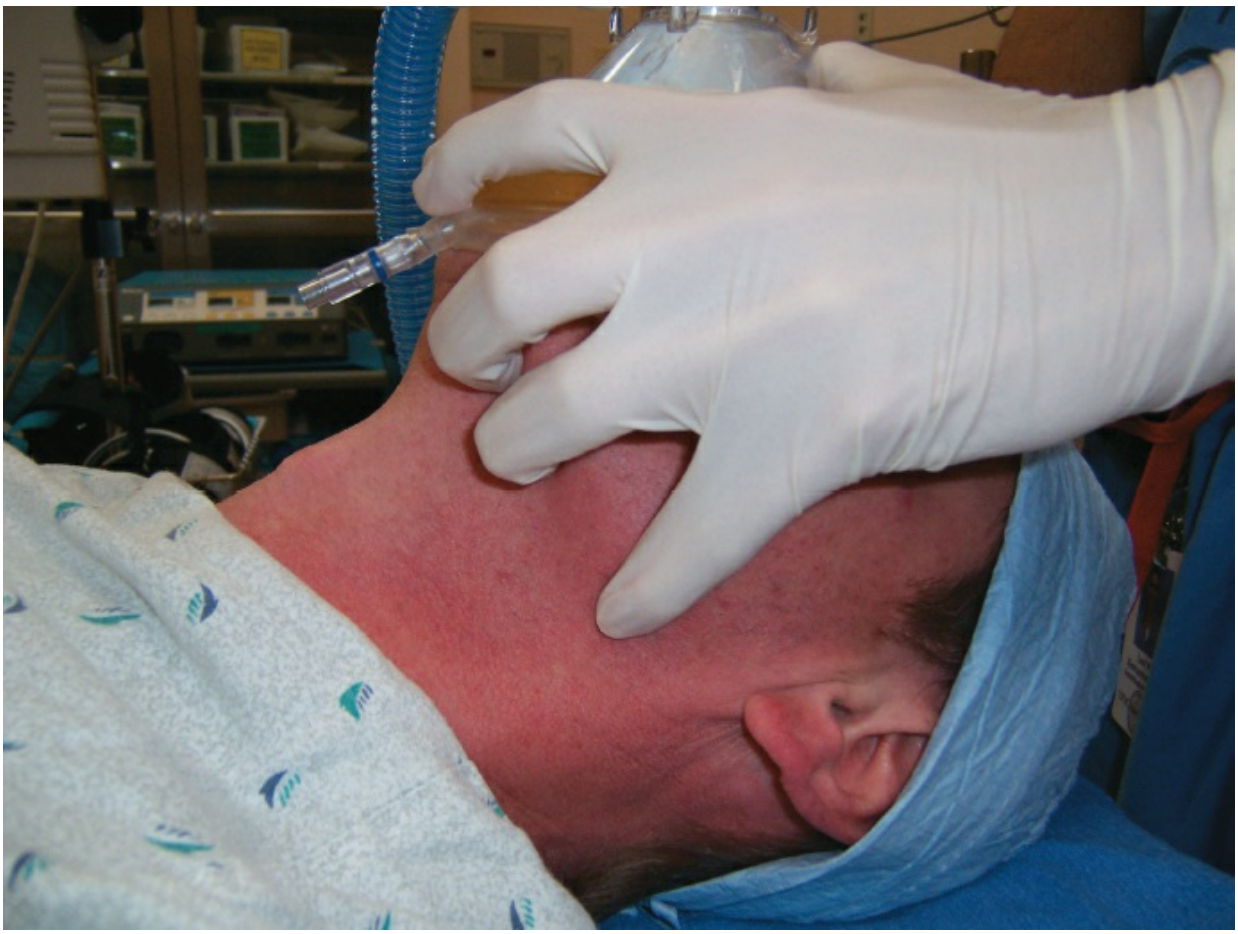

**Figure 4.1.** Effective application of face mask in the unconscious patient, with thumb and forefinger holding mask to face, while the other three fingers pull the mandible up into the mask, creating seal and enacting a chin lift-jaw thrust maneuver simultaneously. (Reprinted with permission from Orebaugh SL, Bigeleisen PE. Atlas of Airway Management: Techniques and Tools . 2nd ed. Philadelphia, PA: Wolters Kluwer Health/Lippincott Williams & Wilkins; 2015.)

Effective ventilation, with resuscitation bag or with an anesthesia circuit, is confirmed by visible chest rise and audible breath sounds, as well as evidence of exhaled carbon dioxide on the gas analyzer (typically present in the operating room, but not outside of it). High inspiratory pressures, over 25 cm $H_2O$, should be avoided if possible, as this may lead force gas into the esophagus, leading to gastric insufflation and risk for regurgitation and aspiration. Use of cricoid pressure during ventilation has been shown to reduce this phenomenon. When insufflation pressures are high, obstruction to airflow should be suspected and addressed. Other causes to be considered include reduced lung or chest wall compliance, pneumothorax, gastric insufflation, and “breath stacking” with insufficient time for exhalation between breaths.

Obstruction to ventilation during BMV is common, and often readily addressed with improved positioning of the head, chin, and jaw. However, in the unconscious individual, both the tongue and soft palate may readily present a barrier to airflow. If improved positioning does not allow for resolution of the obstruction, then an oropharyngeal or nasopharyngeal airway should be utilized. Caution should be used in sizing these devices, or they may be ineffective, or in the case of the oral airway, even contribute to worsening of the obstruction by forcing the tongue into an enfolded position at the back of the oral cavity.

Difficult mask ventilation, defying changes in position or use of an airway, may occur in as many as 5% of cases. Several features are known to increase this risk, including obesity, a history of snoring, increasing age, facial hair (especially large beards) and the edentulous state. When encountering difficulty with BMV, it is helpful to convert to a two-person technique. Typically, this involves a second provider applying both hands to the mask, with forceful jaw thrust, while the initial provider continues with one hand on the mask to help with seal, and the other hand on the bag. If the second provider is not skilled in airway management, he/she is likely to be most helpful by squeezing the bag with both hands while the provider works on mask fit with both hands.

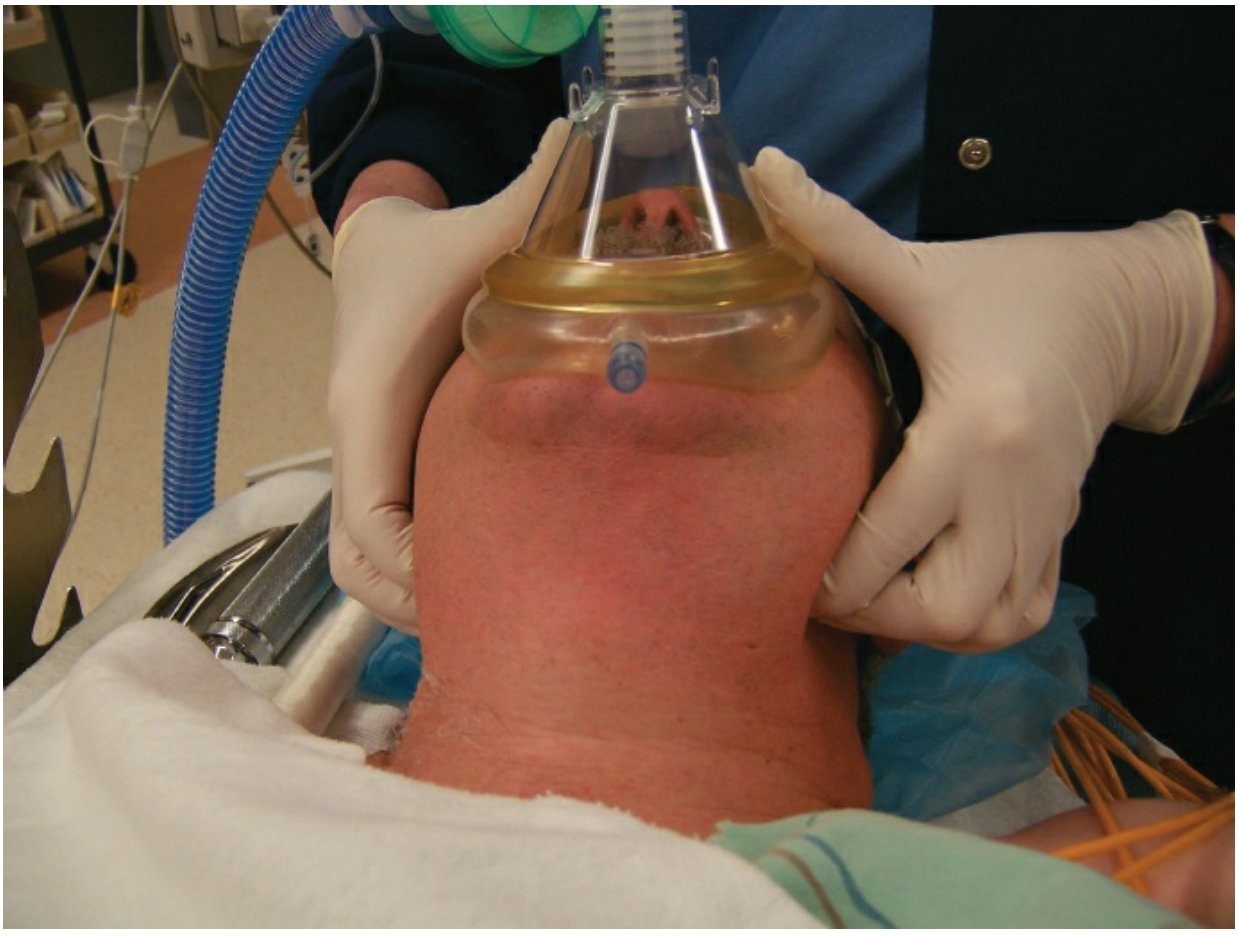

**Figure 4.2.** When only one skilled provider is available, he/she should place both hands on the mask, providing an effective seal, while the unskilled assistant squeezes the bag. (Reprinted with permission from Orebaugh SL, Bigeleisen PE. Atlas of Airway Management: Techniques and Tools. 2nd ed. Philadelphia, PA: Wolters Kluwer Health/Lippincott Williams & Wilkins; 2015.)

Indications for BMV include altered consciousness with inadequate ventilation or hypoxemia, respiratory insufficiency with deterioration impending respiratory failure, apnea for any reason, including cardiac arrest, pre-oxygenation before intubation attempts to maintain oxygenation and avoid severe desaturation during laryngoscopy, and administration of anesthetic gases through certain short anesthesia cases ("mask case"). During resuscitation events, the typical recommended mask ventilation ratio, in relation to chest compression in adults, is 30-to-2 (30 compressions with a pause for two breaths).

There are few contraindications to mask ventilation, especially when a patient is truly apneic or has significant hypoxemia. However, relative contraindications include full stomach or risk for regurgitation, potential cervical spine injury (until inline immobilization is imposed, to prevent cervical spine motion), severe facial trauma with unstable fractures, and upper airway foreign body obstruction, in which case the foreign body should be addressed before ventilation occurs. In all of these circumstances, severe hypoxemia should prompt an attempt at mask ventilation while mitigating or addressing the underlying condition, if possible.

## TAKE HOME POINTS

- BMV is a life-saving skill, the importance of which is often overlooked in the rush to rapid endotracheal tube insertion.
- There is an art to effective BMV, most importantly related to appropriate mask application, which requires experience and consideration.
- While classic teaching is to withhold BMV after induction in "rapid sequence intubation" to reduce the likelihood of regurgitation, the presence of severe hypoxemia outweighs the theoretical concern of aspiration, and oxygen delivery should be provided by BMV in this circumstance, typically with cricoid pressure to reduce gastric insufflation.
- High inspiratory pressures, which can be monitored with the anesthesia circuit, can lead to gastric insufflation as well as pulmonary injury, and should be avoided.
- When obstruction to airflow is suspected as a cause for high pressures or inadequate delivery of tidal volumes, seek to reduce this with improved positioning, more effective jaw thrust, and placement of oral or nasal airways if necessary.
- Rapid ventilation, with inadequate time for exhalation, can lead to breath stacking and high intrathoracic pressures with deterioration of cardiovascular and ventilator

dynamics.

- Many of the adverse consequences of failed intubation are due to hypoxemia; monitor oxygen saturations during attempts at intubation and reinitiate BMV quickly if saturations drop, to avoid perilous drops in oxygenation.

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5

# Optimize the Airway: Direct Laryngoscopy

Steven L. Orebaugh, MD

Endotracheal intubation is frequently required for patients in the operating room, for airway protection and patency during periods of unconsciousness. In instances of respiratory insufficiency, placement of an endotracheal tube (ETT) may be required to provide the requisite support. Indications for intubation include the following:

) Airway patency
) Airway protection
) Inadequate oxygenation
) Inadequate ventilation
) Therapeutic administration of drugs (if no intravenous access)
) Manipulation of pH and/or cerebral blood flow

## Basic Principles

The prime objective during direct laryngoscopy (DL) is to bring the line of sight of the operator into alignment with the opening of the glottis to facilitate placement of the ETT into the airway under direct visualization. Classically, positioning for DL reflects the desire to align the oral, pharyngeal, and tracheal axes, though this is seldom actually possible. A "sniffing the morning air" position, with several towels or a substantial gel pillow behind the head, to align the external auditory meatus to the sternal notch, is an effective starting position for most patients. This alignment may require a greater degree of elevation behind the head/neck/shoulders, or the use of a "ramp" in obese subjects.

The drugs provided for DL reflect the need to ensure the patient is unconscious and relaxed, so that, typically an induction dose of hypnotic is provided, with a fully paralyzing dose of muscle relaxant. Various adjuncts may be utilized in specific situations, such as providing intravenous lidocaine to reduce the impact of DL on intracranial pressure, or administering beta-blocking agents for those with ischemic heart disease. DL may be carried out with a sufficiently deep level of anesthesia without muscle relaxation, but this is less optimal, due to patient movement during the noxious stimulus, the potential for vocal cord closure, and coughing and gagging.

## Direct Laryngoscopy Techniques

Once unconsciousness and relaxation are assured, DL can begin. Most practitioners provide ventilation after the hypnotic is injected, while awaiting muscle relaxation, unless there is concern for regurgitation, as with esophageal disease, reflux, or inadequate fasting. During this phase, cricoid pressure has been shown to reduce gastric insufflation. Once the patient is relaxed, the mouth is opened carefully with the fingers on the teeth in a scissor maneuver, or simply with pressure on the occiput, which tends to extend the head and open the mouth. While data is somewhat contradictory, cricoid pressure is typically applied during DL if the patient is at increased risk of regurgitation and aspiration.

The laryngoscope is held in the left hand, and introduced carefully to avoid intraoral trauma. Both the curved blade and the straight blade are placed on the right side, in an attempt to cordon the tongue off to the left side of the mouth, reducing any obstruction to visualizing the airway. Small motions are utilized, advancing carefully along the tongue, with subtle lifting of this soft, floppy tissue along the way, until the epiglottis is visualized. Blind, deep thrusts should be avoided, due to the potential for trauma and bypassing the actual glottis aperture. Once the epiglottis is in evidence, the tip of the curved blade is carefully advanced in the midline to the junction of the tongue and epiglottis. The reflection of the underlying hyoepiglottic ligament (HEL) may be seen at the base of the tongue as the suspension is applied with the laryngoscope blade, but it is often not visible. Pressure on this ligament, while lifting in a vector that points midway between the ceiling and the feet of the patient, should reveal the larynx and the glottis opening. Care must be taken during this lifting to avoid pulling backward which will cause the blade to pry against the upper teeth.

Once placed against the HEL, with proper lifting dynamics, the curved blade tip should cause a brisk upswing or “flip” of the epiglottis to reveal the glottis opening. The familiar Cormack–Lehane score qualifies the degree of the glottis that is revealed; Grades 1 and 2 permit visible tube passage between the cords, while grade 3 allows only the posterior portion of the laryngeal structures to be seen, necessitating a directed but essentially blind insertion (this may be aided with the use of small, styletted tube to “probe” for the opening, or a bougie, which allows tactile feedback). A grade 4 view, in which no portion of the larynx is visible, is truly without direction, and probably necessitates a different approach, including the use of a videolaryngoscope or fiberoptic bronchoscope, with appropriate attention to the ability to ventilate between attempts, and also to the emergent limb of the ASA Difficult Airway Algorithm, if face mask ventilation should become impossible. Another popular means of describing the visible view of the glottis is the “percent of glottic opening” (POGO) score, which merely quantitates the degree of the glottis aperture that is evident during DL.

If the view of the glottis is poor despite the above maneuvers, adjustments in position may allow a better alignment of the line of sight with the glottis. The logical maneuver is to attempt further extension of the head in order to gain a view of the "anterior" glottis, but this is seldom possible, since true sniffing position involves both lower cervical flexion and substantial extension at the atlantooccipital joint. Instead, pressing on the occiput and further flexing the lower cervical spine to raise the head to a greater degree has the effect of reducing tension on the front of the neck (allowing greater soft tissue displacement), and often improves the glottis visualization.

With the use of the straight blade, the gentle advance down the tongue toward the epiglottis is likewise recommended, but when the epiglottis is encountered, the tip is placed beneath it. With a lifting vector similar to that of the curved blade, again avoiding a "prying" motion which might damage the teeth, the epiglottis is lifted up and out of the way to reveal the glottis. Care must be taken not to insert these slender blades too far, in which case the opening of the esophagus may be revealed, which can have a similarity to the airway in some individuals. Recognition of the arytenoid cartilages and the interarytenoid notch at the posterior portion of the airway opening is therefore important for confirmation of the glottic aperture. The Miller blade is the most commonly available straight blade, and is often furnished as size 3 for adults; however, this is an exceedingly long blade, and the Miller 2 is sufficient for most patients, and provides less temptation to insert the blade too deeply, which increases the risk of esophageal or hypopharyngeal trauma.

Most clinicians prefer the anatomic shape and greater tissue displacement of the curved blade for DL, though it is less "direct" in its mechanism to expose the glottis. Straight blades may be useful in the presence of large, protruding front incisors, restricted mouth opening, or an epiglottis that proves difficult to "flip" with the curved blade, despite correct positioning of the blade tip. In addition, it is acceptable and appropriate if DL with a curved blade fails to switch to a straight blade for a different approach, so long as trauma is avoided and ventilation between attempts is possible. **A maximum of three attempts at DL, before switching to another modality of airway management, is generally acceptable practice.** One disadvantage of the straight blade is the relatively limited exposure it provides; having an assistant retract the lips on the right side of the mouth can improve the ability to place the tube without losing sight of actual glottic entry by the tip of the tube. The straight blade itself should not be used as a guide channel for introduction of the ETT, as this severely hampers observation of tube insertion into the airway.

**The utility of external laryngeal manipulation (ELM), or "bimanual laryngoscopy" cannot be overemphasized.** In one study, over half of DL views were improved by one grade or more with the use of ELM. This maneuver is accomplished

after the blade has been successfully inserted and the epiglottis approached by the use of the left hand; the right hand should be then utilized to palpate and maneuver the larynx on the front of the neck. This allows the two hands to manipulate the larynx for the optimal glottic view. The left hand provides suspension upward by the laryngoscope blade, and simultaneously, the right hand pushes back toward the spine and deviates the larynx to either side, if necessary. In a sense, this creates a tactile familiarity with the airway that is not possible with a one-hand technique. In many cases, ELM will not be necessary to obtain an adequate view of the glottis during DL, but one should practice this maneuver with every attempted intubation so that it becomes essentially a reflex: the blade goes in, and the right hand moves up to the front of the neck. In this way, when ELM is truly needed, it happens automatically, without the need to actually think about it, which can be compromised by distraction or by emergent circumstances. In general, during each DL, all of the maneuvers that can be brought to bear to ensure the highest degree of glottis exposure should be employed—optimum positioning of the patient, appropriate blade choice, experienced operator (or supervisor, during training), adequate muscle relaxation, reflexive use of ELM, and ready availability of capable assistants at bedside. This ensures that the first attempt at DL is the best attempt at DL, with highest chance of "first pass success." It is well known that conditions may deteriorate with each attempt thereafter.

## Placing the Endotracheal Tube

Once optimum glottic exposure is obtained, the ETT is placed, gently and with attention, to not obscure one's own view of the tube entering the airway between the vocal cords. For most practitioners, the stylet affords greater tube maneuverability; it should be removed as soon as the tube tip is clearly past the cords, as the curvature it imparts to the tube may result in difficulty with passage and/or trauma to the anterior larynx. The ideal shape for a tube with a stylet is a "hockey stick" with the stylet being straight all the way to the cuff, at which point it should be bent to adopt this familiar shape. A "rainbow" curvature of the tube is undesirable, as the top of the arc of this curve frequently impacts the palate, during attempts to insert it into the glottis, reducing control of the tip.

When the tube is in place, the cuff is inflated to just seal the trachea; it should be carefully held in place to avoid displacement until fixation. The appropriate depth for a tube is 23 cm for an average man and 21 cm for an average woman, at the front incisors; this is adjusted appropriately for significant deviations in height. Before fixation, the tube's position in the airway should be confirmed by both physical examination (chest rise, breath sounds, ongoing misting of tube) and presence of end-tidal carbon dioxide by capnometry or a color-change indicator. One should bear in mind that, in cardiac

arrest, $CO_2$ may not be detectable, and also that, with esophageal tube placement, this gas may be detectable for several breaths before it steadily decreases to zero thereafter. Recently, the use of point-of-care ultrasound has been described as a means of appropriate tube confirmation as well.

## TAKE HOME POINTS

- DL remains the most commonly utilized method for intubation of the trachea in the operating room.
- The ASA Difficult Airway algorithm guides appropriate action when DL fails to provide a view of the glottis, depending on whether bag-mask ventilation remains possible or not.
- The first attempt at DL should involve optimization of all aspects of the technique, to provide the highest possible "first pass success," since complications increase thereafter.
- Patient position "external auditory meatus aligned with sternal notch," correct blade choice and size, operator experience, and sufficient muscle relaxation are all important precursors to the actual DL.
- After curved blade insertion, the technique of DL should employ a careful search for, and elevation of, the epiglottis (the "light house of the airway"), along with automatic ELM by the right hand, to optimize glottis visualization.
- With the straight blade, the epiglottis is lifted directly by the tip of the blade; improved exposure of the glottis may be compromised by limited room to actually insert the tube.

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6

# Oxygen Is a Drug

Eugene Raggi, MD and David G. Metro, MD

A primary role of the anesthesiologist is to provide oxygen and ensure its delivery to the tissues. As the final electron acceptor in cellular respiration, oxygen is critical to energy generation and therefore to the maintenance of cellular homeostasis and life. However, more is not always better. There are risks associated with the administration of a high fraction of inspired oxygen ($FiO_2$). Harnessing the benefits and avoiding the risks of oxygen relies on an understanding of it as a drug with certain receptor targets and pharmacodynamic effects.

## Administration

Various pieces of equipment exist for the administration of oxygen, with unique capabilities to deliver a desired potential $FiO_2$. In the intubated patient, a known concentration of oxygen is delivered directly to the trachea. Once in the alveoli, this inspired gas with a known oxygen content mixes with gasses comprising the expiratory reserve volume. The final concentration after mixing occurs is indicated by the end-tidal oxygen concentration. Of course, intubated patients, as opposed to those treated with a mask or nasal cannula, are best able to achieve an $FiO_2$ near 1.0.

In the perioperative setting, oxygen is often administered with various other pieces of equipment that do not permit determination of end-tidal oxygen concentration. Use of nasal cannula, facemasks, and facemasks with reservoir bags will result in variable concentrations of administered oxygen. It has been suggested that a nasal cannula can deliver an $FiO_2$ ranging from 0.21 to 0.44, with simple masks and partial rebreathing masks delivering an $FiO_2$ of 0.30 to 0.60, and nonrebreathing masks delivering an $FiO_2$ of 0.60 to 1.0.

While it is impossible to know the precise $FiO_2$ delivered with these pieces of equipment, it is instructive to understand the variables that affect the $FiO_2$. Upon inspiration, administered oxygen of a pre-set flow rate is inhaled. However, if the patient's vital capacity is greater than the set flow rate, this will cause entrainment of

room air or collapse of a tightly fitting mask without vents. Therefore, an increased minute ventilation will require a higher oxygen flow rate to achieve a desired $FiO_2$. Conversely, a lower minute ventilation can be accommodated with lower flows to achieve the same $FiO_2$. While low flows may deliver an appropriate $FiO_2$ in a patient whose minute ventilation is correspondingly low, if a mask is being used, there may be accumulation of carbon dioxide that would have been washed out at a higher oxygen flow rate. The danger in this scenario is exemplified in the following hypothetical patient data from a hypercarbic patient receiving an $FiO_2$ of 0.25:

$$PaO_2 = PiO_2 - \frac{PaCO_2}{R} \qquad (1)$$

In this situation, the oxygen saturation would be reassuring in spite of a $PaCO_2$ approaching a level that may eventually result in $CO_2$ narcosis. In essence, the patient's supplemental oxygen is masking her hypoventilation. Furthermore, low flows in a simple mask may result in rebreathing of $CO_2$ and further hypercarbia with consequent potential morbidity including but not limited to progressive acidosis, $CO_2$ narcosis, and apnea. If pulse oximetry was the only modality to assess respiration, the $CO_2$ narcosis would be missed until desaturation occurred. A blood gas would clearly show the underlying hypoventilation. This scenario demonstrates that the interplay among $FiO_2$, $PaO_2$, and $PaCO_2$ as defined by the alveolar gas equation (Eq. 1) should always be kept in mind. Indeed, deliberate hypoventilation of intubated patients shows that those on high levels of supplemental oxygen will not desaturate as their end-tidal $CO_2$ continues to rise.

## Volume of Distribution

Oxygen diffuses across the respiratory membrane and is taken up by the blood. It exists in equilibrium as a dissolved gas or bound to hemoglobin. While increasing inspired oxygen will result in an increase in the partial pressure of oxygen once hemoglobin is fully saturated, the absolute amount of oxygen dissolved in blood is small as compared to oxygen bound to hemoglobin under normal circumstances. Recall that:

$$PiO_2 = 0.25 \times (760\ \text{mm Hg} - 47\ \text{mm Hg}) = 178\ \text{mm Hg}$$

$$PaO_2 = 178\ \text{mm Hg} - \frac{60\ \text{mm Hg}}{0.8} = 103\ \text{mm Hg}$$

The content of oxygen in blood in mL $O_2$/dL blood ($CaO_2$) equals the sum of the oxygen bound to hemoglobin which is reflected in the first bracketed term and the dissolved oxygen represented by the second bracketed term. Accordingly, a 70-kg patient with a hemoglobin concentration of 15 g/dL, an $SaO_2$ of 100%, a $PaO_2$ of 100 mm Hg and a blood volume of 5 L would have 1,043 mL of oxygen bound to hemoglobin and only 15 mL dissolved in blood.

Delivery of a high $FiO_2$ is termed **hyperoxia**. This is distinct from **hyperoxemia** which refers to elevation of the blood oxygen content above the normal range on room air. Scenarios can be imagined in which hyperoxic conditions may lead to normoxemia such as cases of impaired gas diffusion at the alveolar–capillary interface or when the interface is decreased due to smaller tidal volumes. Hyperoxia can allow for dissolved oxygen to make an important contribution to the total oxygen content of blood especially when the content of oxygen carried by hemoglobin is low due to anemia. Consider the aforementioned patient now in hemorrhagic shock with a Hgb of 5 g/dL, a $PaCO_2$ of 40 mm Hg, and the same blood volume due to crystalloid infusion on an $FiO_2$ of 100%. Using the first term of Eq. 2, the content of oxygen bound to hemoglobin would be 348 mL. At the same time, according to Eq. 1, the $PaO_2$ would be 663 mm Hg. Use of the second term in Eq. 2 demonstrates that under these conditions the content of oxygen dissolved in the blood is 99.5 mL $O_2$. It is clear that the contribution of dissolved oxygen in blood becomes more pronounced at high $FiO_2$ and decreased hemoglobin concentrations.

At high $FiO_2$, oxygen can be concentrated in the alveolus during “preoxygenation.” The mechanism is by washout of the normally present partial pressure of nitrogen in air such that the lungs can contain up to 95% $O_2$ with the remaining 5% as $CO_2$. Assuming a functional residual capacity (FRC) of 2,000 mL, the total oxygen content of the lungs after complete nitrogen washout would be 1,900 mL. An understanding of the relative capacities for oxygen can guide anesthetic practice. Prior to intubation, preoxygenation can extend the time to desaturation. It is best achieved by tidal volume breathing of 100% to an end-tidal oxygen fraction of 90%. It has been shown that by increasing the $FiO_2$ from 60% to 100% for 5 minutes in intubated patients, the apneic time to desaturation below 90% was extended from approximately 4 minutes to 7 minutes plus or minus roughly 1 minute. This indicates the importance of increased pulmonary oxygen reserves in the event of difficult intubation, mask ventilation, or the combination of the two.

## Pharmacodynamics

## Circulatory Effects

Hyperoxia in normal lungs leads hyperoxemia and subsequent chronologic changes in hemodynamics. After seconds of hyperoxia, inhibition of carotid body chemoreceptors has been shown to result in a minor decrease in heart rate. Several minutes of hyperoxia can cause subsequent arterial vasoconstriction. This vasoconstrictive effect has been found to take longer than 60 minutes to reverse once hyperoxic conditions are removed. Systemic vasoconstriction from hyperoxia has been suggested by an increase in systemic vascular resistance (SVR) calculated via thoracic bioimpedance. More specifically this effect has been detected in the coronary circulation by thermodilution and intra-arterial Doppler. Hyperoxia also decreases cerebral blood flow (CBF) due to vasoconstriction of the cerebral circulation. This effect has been assessed by a variety of modalities reviewed in Johnson et al.

The mechanism of vasoconstriction from hyperoxia is thought to be based on two major biochemical pathways. One is due to inactivation of endothelial nitric oxide (NO) by superoxide anions produced by the hyperoxic state. Another is based on in vitro observations that hyperoxia inhibits cyclooxygenase causing a decrease in PGF2α, a potent vasodilator. This mechanism is thought to play a role in the development of retinopathy of prematurity (ROP) in the setting of hyperoxia.

Of particular concern, is vasoconstriction of the coronary circulation during acute coronary syndrome. A paradigm shift may be evolving in the administration of oxygen in this setting as a recent trial has shown larger infarct sizes in the setting of ST-segment elevation myocardial infarction (STEMI) in patients randomized to 8 L/min nasal cannula versus no supplemental oxygen. The study was not powered to detect differences in mortality and morbidity. Hopefully future studies will address this scenario further.

## Pulmonary Effects

The pulmonary vasculature, unlike the rest of the circulatory system, responds to local hypoxia with vasoconstriction. The teleologic purpose of this function is to move blood from poorly ventilated alveoli to well-ventilated alveoli to achieve V/Q matching. Hyperoxia interferes with regional vasoconstriction and alter V/Q matching.

In terms of central control of respiration, hyperoxia initially causes a short-term decrease in minute ventilation that has been shown in healthy volunteers to last on the order of 1 minute. This is hypothesized to be due to carotid body depression. Thereafter, minute ventilation has been shown to increase for at least 30 minutes in healthy subjects. Notably, the degree of stimulation of minute ventilation is dose dependent in terms of the $FiO_2$.

There are various possible explanations for hyperoxic stimulation of minute

ventilation. One is that hyperoxic V/Q mismatching does not allow for proper removal of $CO_2$ at the alveolar capillary interface and increased dissolved arterial $CO_2$ ($PaCO_2$) stimulates central respiratory drive. Another explanation is the Haldane effect wherein oxygenated hemoglobin in the venous system loses its affinity for $CO_2$. This results in an increase in $PaCO_2$ which stimulates central respiratory drive.

Clinical scenarios that require attention to the pulmonary effects of hyperoxia include neonates with congenital heart disease, COPD patients, and one-lung ventilation. In neonates with ductus-dependent congenital heart disease, a decrease in Prostaglandin F2α triggered by hyperoxia will cause closing of the patent ductus arteriosus. In the setting of atrial septal defect, ventricular septal defect, or single ventricle physiology hyperoxia leads to an increase in systemic vascular resistance and a decrease in pulmonary vascular resistance which results in a dangerous decrease in cardiac output due to preferential pulmonary blood flow. The danger of hyperoxia in patients with COPD is related to worsening of V/Q mismatch and the Haldane effect, both of which may increase a patient's already high $PaCO_2$ into a range that may cause $CO_2$ narcosis and subsequent respiratory failure. In the setting of one-lung ventilation, a high $FiO_2$ will vasodilate the ventilated lung increasing blood flow to it and decreasing shunting of blood to the hypoxic, relatively vasoconstricted, and collapsed lung.

## Medical Use

Supplemental oxygen has several medical uses outside of the realm of support of normoxia and homeostasis. Hyperbaric oxygen may have a benefit in the treatment of diabetic foot ulcers. Normobaric supplemental oxygen is administered in cases of carbon monoxide intoxication. Oxygen is also administered for treatment of cluster headaches.

Hyperoxia as a method of decreasing surgical site infection is a topic of controversy. The theory is that hypoxic wound environments have a blunted neutrophil oxidative burst with consequent increased risk of infection. Hyperoxia, by delivering increased substrate for neutrophil oxidative burst, might therefore lead to increased pathogen destruction and a decreased rate of wound infection. However, with some clinical trials suggesting an effect, others showing no effect, and a recent meta-analysis of all trials showing no significant effect on surgical site infection, recommendations as to the routine use of a hyperoxic strategy for the prevention of surgical site infection cannot be definitively made. This same meta-analysis suggested that hyperoxia significantly reduced postoperative nausea but not the composite endpoint of postoperative nausea and vomiting. Interestingly, a posthoc analysis of one of the individual trials, the PROXI trial, suggested a significant increase in long-term mortality and shorter cancer-free

survival in patients subjected to $FiO_2$ of 0.80 versus 0.30 during and 2 hours after abdominal cancer surgery. While this study was not powered to detect this difference between the groups, it does generate a hypothesis that hyperoxia may be harmful to some populations which may be further investigated.

## Side Effects and Risks

While controversy remains surrounding the effect that hyperoxia has on surgical site infection, evidence is growing that suggests the increase in reactive oxygen species (ROS), such as peroxides and hydroxyl radicals, associated with long-term hyperoxia can damage the brain and lungs. Furthermore, the detrimental effect of increased ROS is exacerbated in the setting of ischemia and reperfusion. Hyperoxia has been associated with an increased odds ratio of mortality in the setting of stroke, traumatic brain injury, and cardiac arrest. While these data come from observational and retrospective studies, they suggest consideration of the blood oxygen status of patients admitted with these diagnoses.

Hyperoxia in preterm infants has been known to cause ROP and lung toxicity. This too is thought to be due to increased production of ROS. An $SpO_2$ range of 88% to 94% has been recommended for this population.

In addition to its role as a drug, **never forget that oxygen is also an oxidizer and a member of the fire triad!** Operating room fires can and do occur when an oxygen source is placed in proximity to a fuel source including but not limited to surgical drapes, sponges, towels, and alcohol-based solutions, along with an ignition source such as cautery. As such, **the American Society of Anesthesiology Practice Advisory for Prevention and Management of Operating Room Fires should be known by all anesthesiologists.** With respect to oxygen, the lowest concentration of oxygen that can be tolerated, while avoiding hypoxia, should be utilized in cases of surgery involving the head, face, neck, or airway.

### TAKE HOME POINTS

- Oxygen is a drug.
- Supplemental oxygen can mask hypoventilation and hypercarbia if pulse oximetry is the only method of monitoring sedated patients.
- Hyperoxia can be useful in bleeding, anemic patients as a way to maintain oxygen delivery to tissues.
- Preoxygenation significantly prolongs the time to desaturation.
- Hyperoxia has a variety of pharmacodynamic effects such as:
  - Cerebral vasoconstriction and decrease in CBF

- Coronary vasoconstriction
- Inhibition of hypoxic pulmonary vasoconstriction
- Stimulation of respiratory drive
- Closure of the patent ductus arteriosus

- Until definitive studies assess the risk–benefit ratio of a high $FiO_2$ approach to ventilation in surgical patients, use informed clinical judgment to choose an $FiO_2$ that maintains necessary and sufficient oxygen saturations.
- Minimize $FiO_2$ on surgeries of the head, face, neck, or airway. Always!

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7

# Advantages and Disadvantages of the Laryngeal Mask Airway (LMA)

Paul C. Anderson, MD

An otherwise healthy 57-year-old professional concert singer presents for an elective outpatient prostate biopsy for suspected adenocarcinoma. He has a normal body mass index (BMI) and a class 1 airway. The patient mentions that after an emergency appendectomy ten years ago, he experienced prolonged hoarseness and throat pain. He goes on to say, "I almost sued the guy that jammed that tube down my throat; I couldn't do my concert dates for two months!" Additionally he's had a prior lumbar fusion and has been told he cannot get a spinal. He asks what you would recommend for his anesthetic, and what risks to expect.

## Introduction

In 1983, Dr. Archie Brain introduced the laryngeal mask airway (LMA) as a device to secure the airway without the need for direct laryngoscopy. The LMA was approved for use in the United States in 1991, and has since gained popularity as an alternative to direct laryngoscopy (DL) with endotracheal intubation (ETI) and bag-mask ventilation. It is now an essential piece of equipment on every emergency airway cart and has become nearly ubiquitous in outpatient anesthesia. Despite its many advantages, however, the use of an LMA does carry a small but significant set of risks. Every anesthesia provider should be familiar with the advantages and risks of LMAs in order to better care for and inform their patients (Table 7.1).

**Quick and easy to insert**—Compared to DL and ETI, LMAs are usually easier and faster to insert, and require less skill to place. First attempt success rates vary by model of LMA but are often 70% to 100%, with the LMA Supreme having the highest success rates (over 95%).

**More secure than facemask/bag-mask ventilation**—The LMA allows for easier ventilation than a facemask because gas is delivered distal to the tongue and upper airway soft tissues, therefore decreasing the potential for airway obstruction. Once

secured, it also allows for hands-free ventilation.

**Allows for spontaneous breathing or positive-pressure ventilation (PPV)**—The LMA can be used in a spontaneously breathing patient, or positive pressure can be applied to control ventilation. Muscle relaxants are not required for insertion or maintenance, but may be safely used in certain patients/operations. If PPV is used, inspiratory pressures of up to 20 cm $H_2O$ can be generated with older generation LMAs, and up to 20 to 30 cm $H_2O$ with newer generation LMAs. Average tidal volumes of approximately 500 mL can be safely achieved if the ProSeal or Supreme LMA is used in a healthy patient with a compliant chest wall and compliant lungs.

**Table 7.1 ■ Advantages of the LMA**

- Quick and easy to insert
- More secure than facemask/bag-mask ventilation
- Allows for spontaneous breathing or positive-pressure ventilation (PPV)
- Useful in a wide range of settings
- Less airway morbidity than DL/ETI
- Variety of LMAs to suit the needs of the patient/operation
- Less coughing and bucking on emergence
- Requires less anesthesia to insert and maintain, compared to ETT

**Useful in a wide range of settings**—LMAs can be used in a number of clinical scenarios: as a primary airway device, a rescue device, or a conduit for ETI. The LMA is an integral component of the ASA "Difficult Airway Algorithm", and can be used in both emergent and nonemergent settings. Importantly, if the provider cannot mask ventilate or intubate, insertion of an LMA is the next step directed by the algorithm. Successful oxygenation/ventilation via an LMA may help the provider avoid an emergency airway situation.

**Less airway morbidity than DL/ETI**—Compared to endotracheal tubes (ETTs), LMAs result in lower incidences of postoperative sore throat (19% vs. 32%) and postoperative hoarseness (33% vs. 57%). A recent meta-analysis by Yu and Beirne revealed that patients who received ETTs had significantly higher incidences of hoarseness (relative risk [RR] 2.59), laryngospasm on emergence (RR 3.16), coughing (RR 7.16) and sore throat (RR 1.67) compared to those who received LMAs. Conversely, the authors did not find any differences in incidences of regurgitation, vomiting, nausea or first attempt success in placement between the two groups.

**Variety of LMAs to suit the needs of the patient/operation**—There are a number of LMAs available today. The LMA Classic (the original LMA) is reusable and allows for PPV up to 20 cm $H_2O$. The LMA Unique is a disposable form of the LMA Classic. The LMA Classic Excel is also reusable, but has modifications (including an epiglottis elevating bar) that facilitate intubation through the LMA. The LMA Fastrach/Intubating LMA comes in reusable or disposable forms, has a metal insertion handle to help maneuver the LMA, and allows for blind insertion of a reinforced-ETT through the LMA. The LMA Flexible is either reusable or disposable, and is more flexible than others with kink-resistant tubing. It may be useful for head/neck surgeries. The LMA ProSeal is reusable and features two silicone cuffs, which allow for a better seal and the highest oropharyngeal leak pressure (OLP) of all LMAs (about 30 cm $H_2O$). Additional features include a port that allows for passage of an OG tube, an integrated bite block, and an optional insertion tool. The LMA Supreme is disposable with a single, modified PVC cuff that allows for higher leak pressures (although not as high as the ProSeal), a gastric tube port and a bite block. The Supreme has a slightly modified curve and is the easiest LMA to insert (Table 7.2).

**Improper placement, displacement**—Malpositioning of the LMA may result in difficulty with oxygenation/ventilation. Sometimes this can be the result of a down-folded epiglottis, which causes glottic obstruction. Certain patients may have conditions that preclude proper placement of an LMA—for example, those with airway or pharyngeal tumors, pharyngeal infections, pharyngeal edema, congenital syndromes, etc. In these cases, an ETT may be more appropriate. Similar to ETTs, LMAs do have the risk of becoming displaced or malpositioned during the case, especially upon changes in patient position.

**Improper LMA sizing**—An oversized LMA increases the risk for sore throat, possibly due to greater pharyngeal trauma. Grady et al. found that larger LMA size (5 compared to 4 in men, 4 compared to 3 in women) contributes to a 4x increased risk of sore throat. Further analysis showed the risk for sore throat in the early postoperative period seems to be due to pharyngeal trauma (often from larger LMA) whereas sore throat at 24 hours is most likely due to longer duration of anesthesia (each 10 minute increase in duration increases the risk of sore throat by 33%). Larger LMAs also may take longer and be more difficult to successfully place, and may lead to greater hemodynamic changes.

**Table 7.2 ■ Disadvantages, Risks, and Complications of the LMA**

- Improper placement, displacement

- Improper LMA sizing
- Overinflation of the cuff with pharyngeal complications
- Lower seal pressure and thus limited ability to deliver PPV
- Inability to protect against gastric aspiration
- Risk of laryngospasm with subsequent inability to ventilate
- Other rare complications

An undersized LMA often leads to compensatory overinflation of the cuff to help seat the LMA and improve the seal. Smaller LMAs have greater leaks and may not allow for adequate inspiratory pressures and tidal volumes during mechanical ventilation.

**Overinflation of the cuff with pharyngeal complications—**Manufacturers recommend using the largest LMA possible and inflating the cuff with the minimal effective volume of air to obtain a target cuff pressure of 40 to 60 cm $H_2O$. Ideally this results in an optimal seal, with an OLP of 18 to 20 cm $H_2O$ in first-generation LMAs and 20 to 30 cm $H_2O$ in the ProSeal and Supreme. Inflating the cuff to excessive pressures may lead to increased risk of pharyngeal complications and/or nerve injuries (superior laryngeal, hypoglossal, lingual). Cuff pressure often increases significantly if nitrous oxide is used.

The recommendation by manufacturers of laryngeal mask devices is to maintain cuff pressure below 60 cm $H_2O$. The relationship between cuff volumes and measured cuff pressures is, however, inconstant and not always predictable. Further, some investigators have questioned whether higher cuff pressures are truly associated with pharyngeal complications. In a study by Rieger, Brunne and Striebel, in which patients' cuff pressures were maintained at extremely elevated levels (180 cm $H_2O$) and compared to patients with low cuff pressures (30 cm $H_2O$), the authors surprisingly did not find any differences in pharyngeal complications between the groups. Likewise, Grady et al. did not find any correlation between cuff pressures and complications in their study on LMA size and morbidity. However, Seet et al. found that constantly monitoring cuff pressure (in the LMA Classic) and actively keeping it below 44 mm Hg (60 cm $H_2O$) did result in substantially lower incidences of pharyngeal complications (13.4% vs. 45.6%). Based on these findings, Seet recommends routine intraoperative monitoring of cuff pressure with a manometer. Thus, the relationship between cuff pressures and pharyngeal complications is equivocal, but it appears a more conservative approach is to monitor pressures and keep them below manufacturers' recommendations.

**Lower seal pressure and thus limited ability to deliver PPV—**With the exception

of the ProSeal and Supreme, most LMAs only allow for a maximum of 20 cm $H_2O$ of positive pressure before air leaks around the cuff. The lower seal pressures of LMAs may result in challenges ventilating those patients that may require higher inspiratory pressures during PPV.

**Inability to protect against gastric aspiration**—The incidence of aspiration in LMAs is very rare (0.02%), and there is evidence that newer LMAs (ProSeal, Supreme) minimize this risk. However LMAs do not protect the airway as well as ETTs, and should not be used in patients with a high risk of aspiration. If aspiration does occur, it is often due to LMA malpositioning, gastric inflation, and patient risk factors.

**Other rare complications**—Other complications that have been reported from LMA placement and usage include mediastinitis/retropharyngeal abscess, uvula injury, pharyngeal necrosis, and severe hemodynamic changes.

## TAKE HOME POINTS

- LMAs can be useful in a number of clinical situations and may help avoid many of the risks associated with ETTs.
- There are a variety of LMA types available today, with the ProSeal and the Supreme currently being the most advanced; these models allow for better seals and thus higher inspiratory pressures and larger tidal volumes.
- Although newer LMAs do offer some protection against aspiration, the ETT remains the gold standard for protecting the airway and should be used in cases where there is an elevated risk of aspiration.
- It is unclear whether higher LMA cuff pressures are associated with pharyngeal complications, or whether cuff pressures should be monitored during an anesthetic, though a conservative approach suggests that this is prudent.
- Proper LMA size selection is important to help avoid morbidity.

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8

# Avoiding Challenges With Video Laryngoscopy

Michael Aziz, MD

Since 2003, the use of video laryngoscopy (VL) has grown in clinical practice throughout care settings where tracheal intubation is required. Early evidence clearly demonstrates that improved laryngeal views are achieved with VL compared to direct laryngoscopy (DL). Accordingly, further evidence has demonstrated improved intubation success rates for patients in the operating room who may be difficult to intubate by DL. Furthermore, those less experienced with laryngoscopy appear to achieve higher intubation success rates with VL compared to DL. However, intubation difficulty persists and VL is not universally successful. In settings outside of the operating room and for certain patient populations, the benefit may not be as strong. This section aims to highlight the role of VL for airway management, its difficulty, complications, and tips to avoid difficulty.

## When Should I Do an Awake Intubation Instead of VL?

Certain patients remain difficult to intubate with VL. VL seems to overcome many of the intubation difficulties observed in obese patients and those with a higher Mallampati scale score. **However, patients with head and neck pathologies are at increased risk for intubation failure with VL.** As these patients are also at higher risk for difficult bag mask ventilation and potential surgical airway access, awake techniques with flexible intubation scopes may be the preferred method of airway management.

I am particularly concerned for patients who have received neck radiation. VL, DL, and mask ventilation are all potentially more difficult in this patient population. The good news is that awake flexible intubation may be easier in this patient population. Often their airway is already dry and less sensitive because of the radiation. The stiffness of the radiation changes can make tissue manipulation more difficult with DL or VL, but the airway tends to remain open in an awake patient. The dry, less sensate, and patent airway make awake flexible intubation an excellent choice for airway management.

Patients with cervical spine pathology are likely easier to intubate with VL compared to DL as the indirect approach seems to overcome the difficulty of obtaining an adequate laryngeal view when manual inline stabilization is applied to the neck. However, fluoroscopic studies have failed to demonstrate a consistent reduction in cervical spine motion in this setting compared to DL. Therefore, a flexible technique may result in reduced cervical motion compared to VL when cervical stability is a concern.

Lastly, the success of VL depends quite heavily on the experience of the operator. There appears to be a higher VL failure rate with those with limited experience. The difficult airway should always be approached with caution. The skill of the operator with a particular technique is likely more relevant than the device(s) used to facilitate intubation.

## Should VL Replace DL?

The debate regarding VL versus DL will likely not go away for some time. Beyond obvious cost implications, there are settings where DL may simply be easier than VL. For routine airway management in the operating room in patients without predictors of difficulty, acutely curved VL blades may make intubation more difficult as alignment of tube passage to the glottic opening is less direct. Nonetheless, this difficulty may simply result in a prolonged intubation time on the order of seconds and DL does not appear to be superior to VL in these settings. So, could VL replace DL for routine airway management? Maybe, but there remains a likely role for VL that employs direct blade designs.

**However, there are settings in which DL appears to be superior to acutely curved DL. Despite several observational studies demonstrating improved intubation performance in the prehospital setting, randomized trials have failed to confirm this benefit.** Furthermore, these trials actually suggest superiority of DL over VL. There are several potential reasons for this difference. Again, acutely curved blades rely on an indirect view and good optics. The prehospital patient may be in altered intubating positions, managed in ambient light, and have blood and aspirate in their airway that may contaminate the camera lens. These variables may reduce the efficacy of the video component to laryngoscopy when acutely curved blades are used. Furthermore, inexperience with VL may limit the success for this provider group. Future research is necessary to determine if experience, environment, or blade design can help overcome difficulty with acute angle VL in these emergency environments.

I find that providers struggle to use VL in patients with subglottic stenosis. Often these patients have neck pathologies as identified previously. Providers reach for VL as a difficult airway tool; however, the tube passage is also indirect. An airway with

stenosis may be better suited for tube passage that is direct (e.g., Miller blade, surgical laryngoscopy instruments).

That said, there remains a potential role for VL devices that employ direct blade designs. This technique allows for both VL and DL, so is likely to be at least as effective as DL in a host of environments. These versatile VL systems make a stronger argument for VL to replace DL.

## Overcoming Difficult Tube Placement With VL

Often a good laryngeal view is achieved with VL, but difficult tube passage remains a problem. Training in airway management supports achieving the best laryngeal view for tube passage. However, this may not be the best approach for VL. In one study, an intentionally restricted laryngeal view was associated with easier intubation than a full glottic view when intubation with an acute angle VL was performed. This important difference with VL compared to DL likely relates to the angle of tube passage. When a full glottic view is obtained with a blade inserted deeply, the glottis is suspended in the most anterior configuration. Therefore, the tube needs to make more of a bend to reach the glottis and then a different bend to enter the trachea. When the scope is withdrawn, the glottis falls to a more posterior position and facilitates alignment of tube passage from the pharynx toward the larynx. So, if you have a good laryngeal view but struggle to pass the tube, try withdrawing the laryngoscope. This may compromise the laryngeal view but will likely make tube passage more direct.

Another useful approach to manage the situation of difficult tube placement is to use a flexible intubation bronchoscope alongside the video laryngoscope. In this way the bronchoscope acts as a steerable stylet to advance into the trachea and facilitate tube passage. The optics can be viewed on the VL or on the bronchoscope, but light sources can compromise the optics of either system. So if the VL view is adequate, consider using the bronchoscope without light or video just as a steerable stylet.

The other important modifiable variable relates to patient position. Compared to the ramped or neutral position, the “sniffing” position is associated with greater intubation difficulty with acutely curved VLs. It is likely that excessive neck flexion impairs laryngoscope insertion or tube advancement. For these reasons and others, the obese patient is best managed in the ramped position.

## Avoiding Soft Tissue Injury With VL

Early reports have cautioned regarding the potential of soft tissue injury with VL. Many years since these first reports, studies have confirmed that this problem persists. Clearly, it is the operator, not the device that creates this problem, so it is important to understand the mechanism of injury. Particularly in patients with a limited mouth

opening, there may not be a lot of room to maneuver an endotracheal tube in the oropharynx during tube advancement. When using a rigid stylet, the tube may create pressure on the posterior pharynx while inserting it along the blade. A common error during VL is to keep one's attention on the video screen throughout airway management. Instead, the blade should be inserted under direct vision. Attention should be shifted away from the video and back toward the patient when advancing the tube through the mouth and past the blade. Instead of teaching providers to keep their eyes on the view, we need to train ourselves to shift our attention. I literally cover up the video screen when I hand a laryngoscopist the tube. This forces them to watch the tube enter the pharynx under direct vision.

## TAKE HOME POINTS

- VL is a useful, difficult airway tool, but not for every difficult airway.
- Therefore, do not let your DL skills lapse if you are an experienced airway clinician. If you are a beginner in airway expertise, plan on attaining the same expertise with DL that the more senior folks have. Experience with VL is NOT a shortcut to overall airway expertise.
- The patient with neck pathology is at increased risk for VL failure.
- DL blade designs likely have a lasting role in airway management as acutely curved VL designs can make intubation more difficult. VL systems that employ both blade designs are more versatile.
- The best view with VL may not be optimal! Sometimes compromising the view by withdrawing the laryngoscope blade may facilitate more direct tube passage.
- Consider using a flexible intubation scope as a steerable stylet when VL view is adequate but tube passage remains difficult.
- You must look at the patient (not the screen) when advancing the tube through the oropharynx to potentially avoid soft tissue injury!

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# Do Not Overinflate the Cuff of the Endotracheal Tube

Shawn R. Palmeri, MD

You are supervising a junior resident for the first time and are proceeding nicely through the start of a femoral–dorsalis pedis bypass. You are helping your CA-1 place an arterial line when two senior anesthesiologists make a surprise visit to your room. You have a slight sinking feeling when you notice that one of them is holding a small manometer. He applies it to the balloon of the endotracheal tube (ETT) and you find that the measured pressure in the cuff of the ETT is 65 cm $H_2O$. This particular colleague happens to have a PhD in biomedical engineering (and the other person has an interest in tracheal injuries), so you know that there is not even a chance of arguing about it. You have been busted by the cuff police.

The cuffed ETT is an essential piece of modern anesthesia practice. It serves to seal the airway, decreasing the likelihood of aspirating pharyngeal secretions into the trachea and lungs and allowing adequate positive-pressure ventilation. The ETT cuff also serves to anchor the tube in place, thus allowing position changes during surgery with less risk of mainstem intubation or inadvertent extubation. Traditionally, we learn in anesthesiology that the cuff pressures of the ETT should be within the range of 20 to 30 cm $H_2O$. Although these numbers are very strict in pediatric anesthesia (and a component of every pediatric anesthesiology text), cuff pressure in adults is of key importance as well.

The pediatric airway differs in several ways from that of an adult. One of the key differences is the location of the narrowest portion of the airway. The adult airway is cylindrical, with the tightest area being between the vocal cords or glottis. However, in neonates, infants, and young children, the airway is more funnel-shaped and becomes tightest at the level just below the glottic aperture (the subglottis). Because the pediatric subglottic region can be very narrow, historically there has been concern about using cuffed ETTs in pediatric patients. In some circumstances, even the diameter of an

uncuffed ETT may often be too wide for the airway, despite it being able to be passed through the vocal cords. It is not uncommon in pediatric cases that the anesthesiologist changes to a smaller ETT for this reason.

Regardless of patient age, cuff pressures above 30 cm $H_2O$ for a prolonged operation or stay in an intensive care unit (ICU) may cause local ischemia, resulting in injury to the mucosal lining of the trachea. The initial mucosal damage presents as edema and hyperemia, which can progress to ulcerations and granuloma formation along the mucosa of the pharynx and the trachea. The subsequent formation of scar tissue and strictures, depending on the location, may lead to vocal cord dysfunction, subglottic stenosis, and airway obstruction.

With older ETTs (high pressure, low volume), overinflation of the cuff could result in severe morbidity such as rupture of the trachea, tracheal–innominate artery fistulas, and tracheocarotid artery erosions. The advent of modern single-lumen ETTs (those that are low pressure, high volume), has greatly decreased catastrophic airway complications in the perioperative period, especially for adult cases. However, animal data imply that even overinflation of modern ETT cuffs may result in serious ciliary damage and reduced tracheal blood flow (more severe in hypotensive states). For example, Guyton et al. titled a study using a laboratory model of ETT cuff inflation, "High-volume, Low-pressure Cuffs – Are They Always Low Pressure?" These investigators found that increases in airway pressure caused by decreased lung compliance resulted in higher cuff inflation pressures in all of their experimental groups. Special consideration is required if nitrous oxide ($N_2O$) is used for the maintenance of general anesthesia. $N_2O$ can diffuse through the ETT cuff, and studies have shown that during long procedures this can result in cuff overinflation or even rupture. Although the standard polyvinylchloride ETTs that we use every day is high volume, low pressure, keep in mind that you will occasionally use ETTs with low volume, high pressure, and perhaps not recognize it. For example, laser ETT cuffs are low volume, high pressure.

Fortunately, in modern anesthesia practice the most common complication of endotracheal intubation continues to be postoperative sore throat with incidence ranging from approximately 15% to 50%. In the absence of hoarseness or dysphagia, this is likely due to mucosal irritation from the tube itself, or from trauma secondary to the exertions of direct laryngoscopy rather than signs of permanent airway injury. The use of video laryngoscopy has not been shown to decrease the incidence of postoperative sore throat. Preoperative oral lozenges have shown efficacy in decreasing sore throat after endotracheal intubation and can be continued in the postoperative period.

Cuff pressure is also of importance for patients undergoing thoracic surgery requiring lung isolation with a double-lumen ETT. The cuff on the bronchial lumen can easily be

overinflated and result in bronchial edema and stenosis (as this cuff is often of lower volume and higher pressure than the standard tracheal cuff). Proper practice requires the provider inflate this cuff with only the minimal pressure required to offer adequate lung isolation. Once isolation is no longer required, the cuff should be deflated.

In the operating room, there are limited ways of detecting true ETT cuff pressure in intubated patients. Previous studies have demonstrated that manual palpation of the cuff generally underestimates cuff pressure. A well-performed study from 2004 suggested the use of manometry in gathering accurate data regarding ETT cuff pressure. This suggestion may be taken under stronger consideration in the ICU setting, where patients remain intubated for prolonged periods of time. However, utilization of manometry could well be warranted for longer cases, such as transplants, cardiac surgery, and neurosurgery. This has not gained wide acceptance in clinical practice at this time.

## TAKE HOME POINTS

- ETT cuff pressure has implications in anesthesia. Overinflation of the cuff can result in airway injury.
- ETT cuff pressure is of vital importance in the pediatric population due to anatomic differences in the airway.
- Maximum cuff pressure should not exceed 20 to 30 cm $H_2O$. Special consideration is necessary when using $N_2O$ for maintenance of general anesthesia for long cases.
- Be especially careful to not overinflate the bronchial cuff of a double-lumen tube.
- Manual palpation of the ETT cuff is not reliable in determining cuff pressures.

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# Consider the Use of Lidocaine in the Cuff of the Endotracheal Tube, but Be Aware of the Risks and Alternatives

Jamey E. Eklund, MD and Paul Kempen, MD PhD

Anesthesia providers must mitigate the undesired hemodynamic and neuromuscular responses to intubation. Usually (but of course, not always!), large doses of induction drugs and neuromuscular blockade smooth the way during intubation. Intraoperatively, an adequate level of inhalational anesthetic plus opioids will help the patient tolerate the endotracheal tube (ETT). On extubation, however, the dissipating anesthetic effects and reemerging pharyngotracheal reflexes may lead to coughing and adverse symptoms, including tachyarrhythmias and increased intracranial, intraocular, or intravascular pressures, via the airway–circulatory reflex.

The incidence of coughing at extubation varies between 6.6% and 96%. Mitigating airway–circulatory reflex symptoms is especially important in patients with cardiovascular and reactive airway disease, neurosurgery, and certain head, neck, or ophthalmologic conditions. Multiple anesthetic strategies to prevent ETT-stimulated coughing have been described, including:

) Elimination of the ETT completely during general anesthesia (i.e., mask anesthetics or laryngeal mask airway) or extubation during profound anesthesia when the ETT is no longer necessary (known universally as a “deep extubation”)
) Topical administration of local anesthetic solution to the tracheal mucosa
) Systemic administration of lidocaine or other medications

Anesthesia providers must consider patient history, comorbidities, and surgical needs to select appropriate strategies.

## Intracuff Lidocaine

Nonionized lidocaine has been shown to diffuse readily along a concentration gradient through the lipophilic plastic of an ETT cuff sufficiently to anesthetize adjacent mucosa, typically sparing the vocal cords (which are not in contact with the cuff). The cuff

serves as a reservoir of local anesthetic. Comparing equal volumes of intracuff saline versus lidocaine, the incidence of postextubation coughing has been shown to be 59% versus 38%, respectively. Saline-filled cuffs functioned as the control and were shown to have comparable efficacy to air-filled cuffs. Estebe et al. extensively studied various concentrations of lidocaine (2% to 10%), as well as alkalinization of the lidocaine solution. Higher lidocaine concentrations and alkaline solution pH effectively increase the available nonionized, lipophilic, and diffusible lidocaine. Alkalinization increases the available nonionized and diffusible lidocaine at any given concentration.

**Risks.** Although the use of lidocaine in the ETT cuff is appealing, serious potential risks deserve consideration. These include:

) Systemic toxicity, if the cuff should rupture
) High pressure in the cuff, with tracheal mucosal damage
) Failure to completely empty the cuff before extubation, a slow process, with resultant injury to laryngeal structures.

Plain or alkalinized lidocaine solutions (2% to 4%) are clinically effective while limiting exposure to potentially toxic (gram) amounts of intratracheal lidocaine from 10% solutions, should the approximately 10-mL-volume cuff rupture. Filling and deflating the cuff with noncompressible aqueous solutions typically occur much more slowly than with air, whereas similarly, complete elimination of intracuff air and the pressure–volume effects from $N_2O$ can be difficult. Many studies of intracuff lidocaine (ICL) employed direct manometry to avoid excessive pressure; others inflated cuffs until positive-pressure ventilation at 20 cm $H_2O$ was confirmed without air leak. Prolonged cuff pressure >20 cm $H_2O$ can tamponade mucosal perfusion and result in tissue necrosis. Fluid-filled intracuff pressures may be difficult to assess, with slow fluid flow between pilot and tracheal balloons. Anesthesia providers who are unfamiliar with or unaware of fluid-filled cuffs may not completely empty them at extubation during the 1- to 2-second deflation attempt that is typical for air. Thus, the noncompressible fluid-filled ETT balloon may lead to vocal cord trauma when it is inadvertently pulled through the glottic opening. Although extubation with air-filled balloons was not found to cause arytenoid subluxation in several cadavers, the effect of fluid-filled balloons is unknown.

Albeit rare, cuff rupture has been reported, and lidocaine can be rapidly absorbed through the lung. Although diffusion from 10% lidocaine via intact ETT cuffs did not reach toxic plasma levels, systemic toxicity could occur if the cuff ruptures and releases >1 g of lidocaine into circulation. Cuffs with pinhole-sized defects filled at minimal pressure typically leak slowly, thus limiting peak and rapid uptake and potential lidocaine toxicity. Knight et al. studied high-dose administration of lidocaine in a

patient population to assess systemic toxicity. After induction with 6 mg/kg of lidocaine and maintenance anesthesia of 0.6 mg/kg diazepam and 50% $N_2O$, a total of 21 mg/kg lidocaine via controlled intravenous infusion was administered up to the point of cardiac bypass without toxicity. Peak plasma concentrations of 9.5 mcg/mL were noted at sternotomy. Indeed, rapid parenteral injections carry a higher risk of toxicity; but based on this study, systemic toxicity should not be clinically evident in adults with doses smaller than 100 mg intravenous push or 160 mg via tracheal instillation.

Time-dependent diffusion of lidocaine from the cuff effectively limits toxicity, as hepatic metabolism occurs with a $T_{½}$of 90 minutes. With excessive pressure and resulting tracheal mucosa ischemia, systemic absorption may be further curtailed. In vitro studies demonstrated that higher concentrations of lidocaine (4% vs. 2%), prolonged duration for diffusion (360 minutes vs. 60 minutes), and "priming" cuff membranes (by prefilling them) resulted in a maximum diffusion of only 17.49-mcg lidocaine. A similar independent study noted as much as 1% of a 4% lidocaine solution diffusing after 6 hours, whereas alkalinized lidocaine resulted in 65% diffusion of the stock solution (2 mL of 2% lidocaine) after 6 hours. Sufficient time must elapse for an effective topical accumulation of mucosal lidocaine, making ICL questionably effective in surgeries lasting <1 hour. Typically, cuffs are also prefilled significantly in advance to saturate the cuff membrane and to eliminate air, which may limit clinical utility in high-volume and rapid-turnover practices. Two separate in vivo studies comparing control to lidocaine-filled cuffs showed very significant cough suppression (5% vs. 70% and 16% vs. 38% to 44%, respectively). The primary goal of ICL is to prevent adverse hemodynamic and oxygenation changes. Unfortunately, this occurred with limited success: "The emergent hemodynamic and oxygenation saturation data were similar for all three groups [air, saline, lidocaine]"—Fagan et al.

## Alternatives

Several alternatives to ICL can be utilized, to mitigate coughing and cardiovascular reflexes at the end of surgery. These include:

) Deep extubation
) Intravenous lidocaine
) Topical lidocaine injected into the ETTs
) Use of a specialized ETT, the LITA tube, with distinct injection ports to facilitate local anesthetic delivery to the tracheal mucosa
) Laryngeal-tracheal anesthesia kits

The minimal anesthetic concentration for suppression of the airway–circulatory reflex from the ETT at extubation (MAC extubation or $MAC_{ex}$) is comparable to the

stimulus of skin incision and is effectively managed at 1.2 MAC. Extubation at $MAC_{ex}$ can effectively mitigate hemodynamic and hyperreactive airway responses from tracheal stimulation once the ETT is no longer required. “Deep extubation” involves removing the ETT while the patient is in a surgical plane of anesthesia. Removing the ETT can subsequently reduce anesthetic depth requirements, as surgical stimulation abates and dressings are applied, and can thus expedite emergence and transfer to the postoperative acute care unit. The anesthesia provider must, however, demonstrate airway skills to ensure adequate ventilation throughout emergence. Deep extubation is best performed after spontaneous respiration becomes evident. Removing an unnecessary ETT results in a situation equivalent to anesthesia via mask ventilation and with similar contraindications (i.e., high aspiration risk, difficult airway/high ventilation pressure requirements). Daley et al. showed that most anesthesia providers are hesitant to extubate in a deep plane of anesthesia because of aspiration risk. Thus, placement of a Salem sump (nasogastric tube) after intubation (with removal immediately before extubation) maximizes stomach decompression and helps identify particulate stomach content.

Lidocaine, 1 to 2 mg/kg intravenous push 1 minute before extubation, effectively suppresses cough. Other intravenous medications that can also reduce coughing at extubation include opiates, propofol, succinylcholine, beta-adrenergic blockers, and dexmedetomidine. However, most systemically administered medications, including lidocaine, also increase anesthetic depth, increase sedation, and/or decrease respiratory drive, and thereby unnecessarily prolong emergence from inhalation anesthetics. Lidocaine plasma concentrations of 3 mcg/mL are required to suppress the cough reflex, while contributing 0.15 MAC of anesthetic effects. Animal studies also confirm that as little as 1 mcg/mL of lidocaine contributes significantly to inhalational anesthetic effects. Because many IV medications have antitussive properties, it is clinically difficult to attribute specific mitigation of cough alone to acutely injected lidocaine, without invoking general anesthetic effects per se.

Topical tracheal lidocaine has been effectively demonstrated to reduce the incidence of coughing. Patients undergoing awake fiberoptic intubation are routinely anesthetized topically and are without reaction upon tracheal contact. ETT lubrication with nonaqueous lidocaine jelly may be irritating to the mucosa and is therefore discouraged. Available instillation methods of aqueous solutions include LTA (Hospira, Chicago, IL) at intubation, spraying lidocaine down the ETT tube lumen, or via the LITA tube (Sheridan Catheter Corp., Argyle, NY). The LITA tube has an integrated injection port to allow simultaneous injection above and below the cuff via a separate injection port. Although Gonzalez et al. demonstrated the LITA’s effective in decreasing cough, LITAs are twice as expensive as regular ETTs, can fail when fenestrations become plugged,

and must be inserted at induction for routine use at extubation. An inflated cuff may limit lidocaine from quickly reaching underlying mucosa, while mucosal innervation may be interrupted from above and below the cuff. Likewise, lidocaine may flow beneath the cuff via the film of tracheal secretions. Complete topical effects may require time, whereas systemic transpulmonary effects develop rapidly.

Spraying lidocaine solution down the ETT is a practical and effective alternative to intracuff application. Patients often cough briefly, thus distributing lidocaine throughout the airway and facilitating systemic effects via lung absorption. More effectively, the lidocaine can be trickled in over 10 to 20 seconds via a Luer Lock port on the airway elbow. With the cuff completely deflated, a sustained insufflation/Valsalva maneuver directs the lidocaine upward to the vocal cords and mucosa adjacent the cuff. This is best performed under anesthesia as ventilatory drive returns in response to normalization of the $CO_2$ levels and before complete reversal of neuromuscular blockade, thus facilitating air and lidocaine "bubbling up" through relaxed vocal cords. Upon completion of the injection, neuromuscular blockade is reversed. After typically 20 to 30 seconds, maximal topicalization and a return of regular spontaneous respiration develop. At this point, a rapid deflation of the cuff resulting in no reaction or change in respiration (i.e., as evidenced on tracing) tests to identify adequate topical anesthesia to allow uneventful extubation. This topical effect lasts about 15 to 20 minutes and allows removal of the ETT without significant hemodynamic or respiratory changes. Topically eliminating tracheal stimulus appears to be protective against laryngospasm at all depths of extubation. Although Burton et al. original description recommends 4 mL of 4% lidocaine solution, 5 mL of 2% lidocaine solution is equally effective in our practice. The airway–circulatory reflex is effectively suppressed with 2% lidocaine dosed at 1 mg/kg via intratracheal instillation. The lowest effective dose via intratracheal instillation that effectively mitigates hemodynamic changes immediately before extubation and that has consistent duration of such effects remains to be shown definitively.

## TAKE HOME POINTS

- ICL is effective for cases >1 hour in duration but may carry significant risks and requires significant preparation.
- Lower concentrations of lidocaine are more effective when alkalinized and are less likely to result in systemic toxicity should the cuff rupture.
- Use of manometry is useful to prevent mucosal ischemia but is underutilized.
- Endotracheal instillation appears to be a safe, easy, effective, and widely available technique.

- Clinical skill and experience are required to safely match available techniques to appropriate patients, and the use of intratracheal local anesthetics to remove the ETT is typically contraindicated in patients "at risk" for aspiration.

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11

# An Easy Intubation Does Not Guarantee an Easy Reintubation—Especially After a Carotid Endarterectomy or Cervical Spine Surgery

Steven L. Orebaugh, MD, Heath Diel, MD, and Randal O. Dull, MD PhD

Anesthesia providers do not always appreciate the potential difficulties in reintubating patients who have undergone carotid endarterectomy and cervical spine surgery. Because these patients do not have tumors and usually do not initially present with stridor or signs of vocal cord paralysis (unless there has been a previous stroke), the initial intubation often is uncomplicated. During the operative phase there are many important physiologic issues, such as management of hemodynamics and maintenance of organ perfusion, that compete with the anesthesia provider's attention to airway issues. Prompt emergence and extubation is desired to facilitate postoperative neurologic checks and to avoid hypertension and coughing at the time of emergence. However, at all times, anesthesia providers must be alert for postextubation airway issues. It can be extremely difficult to get the airway secured after failed extubation even if the initial intubation was uncomplicated. This is a situation to consider very carefully before planning a "trial of extubation" or a "let's see how he does without the tube" maneuver.

The causes of postoperative respiratory dysfunction after carotid endarterectomy or cervical spine fusion include laryngeal or pharyngeal edema, hematoma, cerebrospinal fluid (CSF) leak, recurrent laryngeal nerve dysfunction, carotid body dysfunction, cervical fusion, malalignment, and improperly applied bandages.

## Edema/Hematoma

Postoperative cervical edema is present in every anterior neck procedure to some degree and occurs in cervical laminectomy because of prone positioning. In carotid endarterectomy patients, computed tomographic studies have shown a 25% to 60% reduction in airway volume and a 200% to 250% increase in retropharyngeal mass as a result of edema alone. Edema of the larynx and pharynx is thought to be caused by venous and lymphatic disruption, as well as direct tissue trauma with increased capillary permeability secondary to release of local inflammatory mediators. **Tissue**

**edema can be difficult to gauge clinically if the patient has remained in the supine position.** There can be significant internal compression of airway structure with little or no change in neck circumference, and stridor may not be heard until the airway has narrowed to 4 mm. Also, unilateral tissue disruption can cause bilateral edema. Edema is rarely the sole cause of respiratory distress leading to reintubation, but it compounds the effects of other problems that might arise (such as hematoma) and can make visualization of the vocal cords for reintubation extremely difficult. If the edema has occurred because of prone positioning, elevating the head of the bed to 30 degrees during emergence can reduce soft tissue edema.

Significant hematoma occurs in about 1.4% to 10.0% of carotid endarterectomy patients, with higher frequency in cases involving coagulopathies and heparin use without reversal. Frequently, hematomas do not develop until several hours into the postoperative phase, and the "carotid take-back" patient is often hypertensive, hypercarbic, and partially obtunded as well. Reintubation in this situation can be one of the most difficult airway situations to manage, and the airway can quickly become a truly emergency situation. Surgical evacuation of the hematoma without regard for aseptic technique may be sufficient to relieve the obstruction until oral direct laryngoscopy can be performed. **The authors recommend that anesthesia providers have available maximum airway support in terms of personnel and equipment when reintubating any patient who has developed significant hematoma after carotid or cervical neck surgery.**

## Cerebrospinal Fluid Leak

CSF leak is a possible complication of anterior cervical vertebral fusion and occurs when the integrity of the dura mater and arachnoid tissue is disrupted. Collection of CSF can cause impaired ventilation as a result of mass effect, very similar to hematoma formation.

## Recurrent Laryngeal Nerve Injury

Recurrent laryngeal nerve injury happens most often after thyroid surgery but is a recognized complication of carotid endarterectomy and anterior cervical spine surgery as well. Acute dysfunctions of the recurrent laryngeal nerve occur in about 0.2% to 10.0% of carotid surgery cases, but, fortunately, less than 1.0% involve permanent injuries.

The recurrent laryngeal nerve runs in the groove between the trachea and esophagus and innervates all the muscles of the larynx except the cricothyroid muscle. Injury is usually the result of ischemia, surgical manipulation, dissection, stretching, or compression. Unilateral dysfunction results in unilateral vocal cord adduction and

hoarse voice. Bilateral dysfunction causes airway obstruction from bilateral cord adduction. The anesthesiologist should be aware of the preoperative function of the recurrent laryngeal nerves and patients with hoarse voice related to stroke or prior surgery. These patients may benefit from preoperative evaluation. Upon emergence and extubation, bilateral laryngeal nerve dysfunction presents as immediate airway obstruction requiring intervention.

## Carotid Body Dysfunction

The carotid body functions primarily as a chemoreceptor for blood oxygen and carbon dioxide content. Surgical denervation secondary to carotid endarterectomy impairs the patient's physiologic response to hypoxia. Patients treated with respiratory depressants such as opiates are at greater risk for postoperative hypoxia.

## Cervical Misalignment

Cervical misalignment is an unusual but possible complication of cervical spinal fusion. Misalignment can cause structural impingement of the airway, which, coupled with edema, can lead to ventilation deficiencies. Also, cervical fusion limits neck extension, and this could contribute to difficult postoperative reintubation.

## Surgical Dressings

Supportive dressings after neck surgery can cause airway obstruction by impeding venous and lymphatic drainage and worsening edema. Large dressings also obscure visualization of the operative site and may cover signs of bleeding that would alert the anesthesia and postoperative acute-care staff to a developing hematoma. Cervical collars should be sized appropriately and allow for some postoperative expansion due to edema. It should be obvious but bears stating that excessively tight or circumferential neck bandages should never be used. The authors are aware of several cases of apparent airway obstruction after carotid endarterectomy that were relieved when the neck dressing was removed.

### TAKE HOME POINTS

- In addition to the specific pathologic situations described above, it has become increasingly apparent that extubation of the trachea is not uncommonly a precarious intervention for patients in the operating room or recovery areas, or those in the ICU.
- The most recent ASA guidelines suggest that "an extubation strategy is a logical extension of the intubation strategy."
- Recommendations include consideration of clinical factors that could impact airway

patency or ventilation after extubation (as detailed above), development of an airway management plan that can be immediately applied if ventilation fails on removal of the tube, and potential use of an airway stylet or supraglottic airway as a guide for reintubation.

- In the most recent iteration of the National Audit Program (NAP4, 2011) from the United Kingdom, over 20% of morbid events related to airway management occurred at the end of anesthesia or in the recovery area after extubation. These data underscore the importance of a management plan for airway management should obstruction develop after removal of the endotracheal tube.

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12

# Plan for an Airway Fire With Every Head and Neck Case

Julie Marshall, MD

A 67-year-old woman with a history of chronic obstructive pulmonary disease (COPD), home oxygen requirement of 3 L/min by nasal cannula, and coronary artery disease was admitted to the burn unit. She had been involved in a house fire after falling asleep while smoking and dropping her cigarette. She sustained an inhalation injury and was intubated in the intensive care unit (ICU) for 2 weeks before coming to the operating room (OR) for a tracheostomy. The procedure was done using the in situ polyvinyl chloride endotracheal tube. During the procedure, you had trouble maintaining her blood pressure under anesthesia and were reluctant to use pressors due to recent skin grafts. Because she was tolerating only about 0.5% isoflurane and not much midazolam, you added 20% nitrous oxide to her inspired oxygen. Unfortunately, she suffered a desaturation of her $SpO_2$ with attempts to further lower the $FiO_2$. As the airway was entered with electrocautery at the tracheostomy site, a flame was noted that flashed from the tracheostomy. What might have been done to decrease this risk? Now that a fire has occurred, what should be done?

## Introduction

One of the responsibilities of the anesthesia provider is the management of the operating room environment, including prevention and management of operating room fires. Selecting an anesthetic plan that decreases the risk of fire is one of the first priorities in airway management. If a fire does occur, an anesthesia provider must know what to do to minimize harm to the patient.

## Fire Triad

The risk of fire occurs whenever the fire triad is present. The fire triad consists of an ignition source, fuel, and oxidizer. It must be recognized that these elements are nearly always present in the OR! During the head and neck surgery, these elements are not only

present but in close proximity. The oxidizer (oxygen or nitrous oxide) is provided by the anesthesiologist through the endotracheal tube into the surgical site. The ignition source is provided by the surgeon, usually in the form of an electrocautery device or laser for airway fires. The fuel source varies with the type of surgical procedure.

**Common Components to Fire Triad in an Operating Room**

| Oxidizer | Ignition Source | Fuel |
|---|---|---|
| Oxygen | Electrocautery | Endotracheal tube |
| Nitrous | Lasers | Packing |
| | Fiberoptic lights | Patient tissue |
| | Defibrillator pads | Drapes or gowns |
| | | Surgical prep solutions—not dried |
| | | Patient's hair |
| | | Nasal cannula or facemask |

## Procedures With Increased Risk for Fire

Common procedures that carry a high risk of airway fire include tracheostomy, tonsillectomy, adenoidectomy, airway tumor debulking, and tracheal reconstructions. Head and neck procedures or ophthalmologic procedures requiring sedation with supplemental oxygen create a high risk of an operating room fire by trapping oxygen under the drapes, creating an oxygen-rich environment.

## Surgical Fire

If an endotracheal tube is ignited in a patient, the flow of gas through the tube can create a "blowtorch"-type flame that can injure more distal structures. Fires that occur at tracheostomy sites as the airway is entered have the potential for local injury, flames that enter the OR environment, or injury to the distal lungs. Oral and pharyngeal procedures performed in children with uncuffed tubes may result in airway fire because of the leak of oxygen-rich gas into the site of surgery.

The endotracheal tube is the fuel source most consistently present in the airway. It has been shown that red rubber, polyvinyl chloride, and silicone endotracheal tubes are all flammable at lower than 27% oxygen. Commercially available "laser-resistant" tubes are more resistant to combustion and are the recommended endotracheal tube

when the use of a laser is planned. Filling the cuff of the endotracheal tube with saline tinted with methylene blue allows notification to the surgeon of cuff perforation if damage has occurred.

For procedures involving the head and neck, when moderate to deep sedation are required, or in a patient with oxygen dependence, the anesthesiologist should consider a sealed gas delivery system such as a cuffed ETT or LMA. If the patient and case are deemed appropriate for an open gas delivery device (facemask or nasal cannula), care must be taken to avoid trapping of gases under drapes thereby creating a high-oxygen environment. In a closed claims analysis of operating room fires from 1985 to 2009, a large proportion of electrocautery-induced fires occurred using an open gas delivery system. The necessity for an endotracheal tube should be discussed with the surgeon as some procedures may be performed with intermittent apnea, although this may require a higher $FiO_2$ during episodes of ventilation.

## Communication and Prevention

The surgeon and anesthesiologist should be in communication about the surgical plan throughout the case. The anesthesia provider should be notified as the airway portion approaches so that adjustment may be made to lower the $FiO_2$ if needed.

Minimizing the $FiO_2$ is one of the trickiest aspects of managing the fire triad, even for experienced anesthesia providers. It is especially difficult in patients who have poor lung function or tenuous cardiovascular status. If there is difficulty in maintaining the patient at a low $FiO_2$, the surgeon must be notified so that he or she can use non–heat-generating surgical tools (scalpel instead of electrocautery) or modify the surgical plan. During intraoral or pharyngeal procedures, wet packing may be placed to decrease the leakage of oxygen-rich gas into the surgical site. Care must be taken that these stay moist, because dry packing will act as an additional source for ignition.

## Management of OR Fires

If an airway fire occurs, **immediate action** must be taken to prevent further harm. The most recent Practice Advisory for the Prevention and Management of OR Fires by the ASA provides the following steps in the Operating Room Fires Algorithm when airway fire is present: (1) Remove the tracheal tube, (2) Stop the flow of all airway gases, (3) Remove sponges and any other flammable material from the airway, and (4) Pour saline into the airway. A carbon dioxide fire extinguisher may be used if the fire is not extinguished following these steps. If a fire continues in the OR, activate the fire alarm and evacuate the patient.

Assuming the fire was extinguished with the initial steps, the anesthesiologist should

reestablish ventilation by mask without supplemental oxygen or nitrous oxide if possible; extinguish the airway device and attempt to determine if airway fragments could be left in the airway. Consider bronchoscopy, if needed to retrieve parts of the tube or assess the degree of injury to the airway. Any additional relevant workup (arterial blood gas, chest x-ray) or treatment including airway support (reintubation, tracheotomy) should be implemented.

For an OR fire not involving the patient airway, the airway device should be left in place. Remove all drapes and burning materials and extinguish flames with saline or a fire extinguisher appropriate for use in the OR. For all operating room fires, reporting to the local fire department should occur, based on local policy. All such cases should be evaluated within an institution's quality reporting framework, to improve future patient outcome.

So what could have been done differently for the patient above, who sustained an airway fire during tracheostomy? A discussion between all providers should occur prior to the procedure to determine the risk for airway fire. **The steps for management if one does occur should be outlined, and agreed upon**. Using a gas mixture of oxygen and air would have decreased the amount of oxidizer present. Notifying the surgeons of the increased $FiO_2$ requirement may have resulted in an alternative method of entering the airway, such as a scalpel. And finally, all operating room personnel including the anesthesia providers should participate in periodic OR fire drills to plan for the potential of an OR fire.

## TAKE HOME POINTS

- The fire triad is both present and in close proximity to the airway in the cases noted above—develop a method to remind yourself of that for every case with airway fire potential.
- Minimize oxidizer $FiO_2$ and nitrous oxide concentration for cases with risk of fire.
- Minimize ignition generators—electrocautery or laser time.
- Laser tubes are harder to ignite, but note that all tubes can combust.
- If an airway fire occurs, disconnect from the circuit, extubate, extinguish the flame, ventilate without supplemental oxygen if possible, evaluate, and support the airway as needed.

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13

# There Are Special Considerations Involved With Both Intubation and Chronic Airway Management of Burn Patients

Joshua Knight, MD

Burns can result from thermal, chemical, electrical, or radiation injury. Carbon monoxide poisoning is the most frequent cause of death during and immediately after a fire. If the patient survives the first few hours, morbidity and mortality are related to the total body surface area (TBSA) involved, the depth of the burn, and the patient's age. **The likelihood of airway compromise increases with more serious burns.**

Characteristics of **major burns** include:

- Partial-thickness burns involving >25% of TBSA in adults
- Full-thickness burns involving >10% of TBSA
- Presence of inhalational injury
- Involvement of the face, eyes, ears, hands, feet, or perineum causing impairment
- Caustic chemical burn etiology
- High-voltage electrical burns
- Burns in patients with coexisting debilitating disease

**Table 13.1 ■ Rule of Nines**

| | |
|---|---|
| Entire head and neck | 9% |
| Each arm | 9% |
| Anterior upper/lower trunk | 18% |
| Posterior upper/lower trunk | 18% |
| Each lower extremity | 18% |
| Genitals and perineum | 1% |

| | |
|---|---|
| Each hand | 1% |

Characteristics of **moderate burns** include:

- Partial-thickness burns involving 15% to 25% of TBSA in adults
- Full-thickness burns involving 2% to 10% TBSA

TBSA of burned skin is estimated using the "rule of nines" Body parts are divided into allotments or multiples of 9% (Table 13.1).

## Acute Management

Burn patients with inhalational injury may require endotracheal intubation and ventilator support in the field. If the patient has an endotracheal tube (ETT) on arrival to the hospital, **do not change the tube;** it may be difficult to get another one in place.

**Burn patients can present with asymptomatic airways, but can shortly become problematic because of subsequent respiratory sequelae that lead to a challenging airway**. Burn patients develop excessive amounts of upper- and lower-airway edema as a result of mucosal destruction and capillary leakage that is further exacerbated by fluid resuscitation. Airway edema and narrowing continue for 12 to 24 hours after the initial burn insult. A thorough history and physical are helpful in determining which patients are candidates for early intubation. While assessing the patient, administer oxygen by facemask and monitor oxygen saturation with pulse oximetry.

**History.** A burn injury that occurs in an enclosed space with highly combustible material is very suspicious for inhalation injury. Patients who report coughing, drooling, hoarseness, dysphonia, and dysphagia are at risk of airway swelling.

**Physical Exam.** Facial burns and the presence of oral soot correlate highly with airway edema and impending airway compromise. Other signs include singed facial hair, soot in the nose, stridor, and respiratory distress.

**Diagnosis.** The diagnosis of inhalation injury is made primarily by history and physical examination. Patients who demonstrate the above signs and symptoms should undergo prompt endotracheal intubation. Testing supportive of intubation include partial pressure of arterial oxygen ($PaO_2$) <60 mm Hg, $PaCO_2$ >50 mm Hg (acutely) on room air, or a $PaO_2$ <200 mm Hg on 100% oxygen. The gold standard for diagnosis is fiberoptic bronchoscopy. Computed tomography (CT) scans and radiographs of the chest are not helpful in the acute setting. Some facilities advise using fiberoptic laryngoscopy every 3 to 4 hours to diagnose impending airway

obstruction.

**Management.** Initial management includes securing the airway, breathing, and circulation (ABC) as in any other form of trauma. If the patient's history and physical are indicative of airway compromise, perform endotracheal intubation early before it becomes a technical challenge. Inform the entire team of physicians of the primary approach and alternative plans for managing the airway. Difficult airway equipment should be readily available, including staff capable of rapidly performing an invasive airway if needed. If a "can't ventilate, can't intubate" situation arises, the physician should approach the airway based on the Difficult Airway Algorithm.

The most suitable elective methods of securing the airway in a burn patient are discussed below:

- Direct vision laryngoscopy is the most commonly used technique for endotracheal intubation. If the patient has inadequate mouth opening, limited range of neck motion, and distorted postburn airway anatomy, alternate routes of intubation should be considered earlier rather than later. Videolaryngoscopy has proven useful in many arenas of airway management and there are limited but encouraging data in the burn population that they may have improved glottic visualization and require fewer attempts than direct laryngoscopy.
- Flexible fiberoptic laryngoscopy is the alternative method of choice if mouth opening and/or neck motion prove to be limited.
- Retrograde wire technique is useful when bleeding prevents adequate visualization of the airway. This is best performed by a provider with experience.
- Tracheostomy is done electively in a sterile environment, usually by a surgeon. Surgical tracheostomy in patients with burns does carry increased incidence of pulmonary sepsis, subglottic stenosis, fistula formation, and subsequent death.

Succinylcholine, a depolarizing muscle relaxant, should be avoided when intubating burn patients. **Succinylcholine can produce dangerous levels of hyperkalemia,** leading to bradycardia, dysrhythmias, and cardiac arrest. This is predominately due to proliferation of extrajunctional receptors, and administering succinylcholine more than 24 hours after an acute burn injury is considered contraindicated.

Be careful when using nondepolarizing muscle relaxants initially. Because there is a possibility of failed intubation, the patient may need to have spontaneous ventilation reestablished. Interestingly, burn patients are generally resistant to the effects of nondepolarizing muscle relaxants after the acute phase of injury. This desensitization appears by postinjury day 7 and may last up to 70 days.

Nasotracheal intubation is suggested if facial trauma or burns do not preclude its use as patients requiring intubation for an extended period of time may tolerate this method

better. The risk of sinusitis increases after 4 days of nasotracheal intubation. Do not extubate patients who require multiple repeat surgeries until the planned surgical course of treatment is completed. If extubation occurs, the provider may run into the same problems faced acutely as well as complications that occur in the chronic setting.

Dressing changes, irrigation, and debridement of the wound are common procedures done in the early days after burn injury. If the patient does not require airway support with intubation, these procedures can be done under monitored anesthesia care with mask ventilation. Short-acting medications such as midazolam, propofol, and ketamine are the anesthetic agents of choice.

High-frequency positive-pressure ventilation (HFPV) is beneficial in preventing barotrauma and pneumonia in patients with inhalational injury. Tidal volumes of 1 to 3 mL/kg are given at frequencies of 100 to 3,000 cycles per minute. This method of ventilation allows adequate recruitment of collapsed alveoli while avoiding high peak airway pressures. Proper gas humidification is required to avoid severe necrotizing tracheobronchitis.

## Chronic Management

After primary treatment and recovery from burns, patients can present with other complications that have separate and equally important implications for airway management. Chronic complications in burn patients include tracheal stenosis, wound contracture of the neck and chest wall, and scarring of airways and lung tissue. These issues can make both intubation and mechanical ventilation more difficult.

**History.** Patients with third- and fourth-degree burns are likely to develop scar contractures. Face and neck contractures can make intubation challenging by preventing adequate oral opening, neck flexion, and head extension. Contractures in patients with circumferential full-thickness chest wall burns have problems with chest wall motion, decreasing the ability to ventilate the lungs adequately.

Direct inhalational injury, scar contracture, and/or mechanical damage from the ETT, tracheostomy tube, or their respective cuffs put burn patients at risk for tracheal stenosis. Stenosis can be worsened by pressure necrosis with subsequent healing and scar formation. Patients may report dyspnea or may have a history of requiring smaller ETTs for repeated intubations.

**Physical.** Findings of stenosis are made by fiberoptic bronchoscopy. Most stenoses occur in the subglottic region, but they can also involve the upper and lower trachea or a combination of these. Stridor is indicative of severe or worsening stenosis.

**Management.** Tracheal stenosis is difficult to treat once it occurs. Prevention is the key to management. Although inhalational injury causes tracheal stenoses in and of itself, the risk can be decreased by using low-pressure cuffs (<20 cm $H_2O$), ensuring tube stability, and minimizing the number and duration of intubations. Early tracheal resection should be avoided because of high restenosis rates.

More adequate planning of airway instrumentation and successful intubation is permitted in later presentations of burn patients. If neck motion or tracheal stenosis is a concern, it may be best to forego conventional laryngoscopy and opt for videolaryngoscopy or even awake fiberoptic techniques. If intubation and ventilation both prove difficult, the use of a supraglottic airway such as an LMA can allow more time to prepare for airway instrumentation, with some models such as the i-Gel being more effective. As stated previously, maintain open communication with the surgical team. When endotracheal intubation is needed emergently, their surgical skills will be required to release wound contractures to make head and neck manipulation less difficult, or they may be needed to secure a surgical airway.

## TAKE HOME POINTS

- A detailed history and physical examination are essential in predicting airway compromise.
- It is safer to intubate sooner rather than later.
- Avoid succinylcholine.
- Elective tracheostomy in burn patients is associated with a high incidence of complications.
- Utilize a team approach. Maintain open communication with the surgical team.
- Have the appropriate equipment and personnel to manage a difficult airway readily available.

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# To PEEP or Not to PEEP—That Is the Question

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You are an anesthesiology resident working at a large academic tertiary care center, and have been called to the Emergency Department to help with a major trauma. The patient is a 27-year-old male with no known medical history who was an unrestrained passenger in a motor vehicle accident earlier in the evening; now brought to the trauma bay after a prolonged extrication. On presentation, the patient's vitals are within normal limits except that his pulse oximeter shows an oxygen saturation of 88% and he appears dyspneic. He is complaining of tenderness along his right chest wall and it appears that he may have several broken ribs.

The Emergency Department attending, concerned about impending respiratory failure secondary to pulmonary contusion and rib fracture pain, asks that you intubate the patient and initiate positive pressure ventilation in order to prevent further derecruitment and correct ventilation/perfusion mismatch. You sedate the patient, intubate without complication, and add 8 cm $H_2O$ of PEEP on your ventilator settings. Two minutes later, you notice that the patient's blood pressure has dropped significantly and he is now tachycardic. Examination reveals decreased breath sounds on the right side, distended neck veins, and tracheal shift to the left. The ED attending asks you what is happening—how should you answer?

Whether delivered directly through a mechanical ventilator or through a tight-fitting facemask, the appropriate use of positive end-expiratory pressure (PEEP) can increase arterial oxygenation in both healthy and pathologic lung states. However, inappropriate use of PEEP can have significant harmful effects, such as in the case above where PEEP in the presence of a pneumothorax can lead to worsening hemodynamic parameters and eventual cardiovascular collapse. As such, this technique requires a well informed and astute clinician to maximize its benefits. This chapter will discuss the clinical aspects of PEEP, including common indications and contraindications, in order to aid decision making as it relates to patient care.

## Definitions

PEEP can be defined as the pressure in the lungs above atmospheric pressure that exists at the end of expiration. There are two types of PEEP: extrinsic and intrinsic.

- **Extrinsic PEEP**—also called applied PEEP, is the mechanical ventilator maneuver of exerting supra-atmospheric pressure at the end of expiration. It is this aspect of PEEP that is most commonly referred to during anesthesia. It is important to recognize that PEEP is not a ventilator mode by itself; rather it is an adjunctive treatment that can be applied to all forms of mechanical ventilation: controlled, assisted, or spontaneous.
- **Intrinsic PEEP**—also called auto-PEEP, refers to a complication of incomplete expiration and subsequent air-trapping. Intrinsic PEEP has three main causes:
  1) High respiratory rate or large tidal volume—an increase in either variable has the same result; a new breath being initiated before completion of the last exhaled breath.
  2) Restriction of expiratory flow—occurs frequently in patients with COPD and other chronic lung disease; expiratory flow is limited due to airway constriction, requiring longer expiration time.
  3) Increased expiratory resistance—may occur because of a kinked or narrow endotracheal tube. Increased resistance to airflow results in longer required expiration time.

## Physiologic Effects

### Respiratory

The major effect of PEEP on the lungs is to increase the functional residual capacity (FRC) above closing capacity; thereby leading to the stabilization and expansion of partially collapsed alveoli. Additionally, PEEP improves lung compliance by shifting the tidal volume to a more compliant portion of the pressure–volume curve. The overall effect is a decrease in intrapulmonary shunting, improvement in arterial oxygenation, and a decreased work of breathing. As a result, improvement in the arterial oxygenation may be achieved with a lower fraction of inspired oxygen ($FiO_2$) and therefore the risk of oxygen toxicity is reduced.

### Cardiac

Adverse cardiovascular effects of PEEP can include progressive reductions in cardiac output as mean airway pressure, and secondarily, mean intrathoracic pressure, increases. The principal mechanism appears to be progressive decrease in venous return to the heart, however another mechanism which is postulated is that of leftward displacement of the interventricular septum, which interferes with left ventricular filling

and LV compliance (increased LV afterload). This occurs because of an increase in pulmonary vascular resistance (increased RV afterload) from distension of the alveoli. Above 15 cm $H_2O$ PEEP, RV volumes increase and RV ejection fraction decreases, consistent with increased RV afterload. It is important to note that intravenous fluid administration can partially offset the effects of PEEP on cardiac output. Stated in another way, patients with decreased intravascular volume are more susceptible to circulatory depression as a result of PEEP than those who are euvolemic.

## Central Nervous System

As discussed above, PEEP increases intrathoracic pressure and results in an increase of right atrial pressure. This increase in pressure is translated to the cerebral veins via the superior vena cava and jugular veins; thus causing a decrease in cerebral venous drainage and possible increase in intracranial pressure (ICP). This, combined with a fall in cardiac output leads to a decrease in cerebral perfusion pressure (CPP). In a healthy brain, autoregulation ensures continued adequate cerebral perfusion despite these changes, however studies are conflicting regarding whether a patient with brain injury/pathology will also be able to compensate. For this reason, PEEP should be used with caution in this population of patients.

## Renal

Ventilation with PEEP causes a reduction in urinary output, sodium excretion, and creatinine clearance. The decrease in cardiac output and mean arterial pressure causes low-pressure baroreceptors to discharge (increased sympathetic activity) which raise plasma antidiuretic hormone concentration and decrease urine output. The reduction in renal perfusion stimulates the renin–angiotensin system, resulting in increased aldosterone production with subsequent increases in water and sodium reabsorption. Reduced venous return causes a decrease in right atrium release of atrial natriuretic peptide. While these effects are not significant to a healthy kidney, they may exacerbate the situation if associated with other comorbities.

## Hepatic

Hepatic blood flow depends on a balance of flow through the hepatic artery and portal circulation. The reduction in cardiac output associated with PEEP leads to a proportional reduction in hepatic blood flow. In addition, raised intrathoracic pressure leads to increased hepatic venous congestion, which has a deleterious effect on portal vein blood flow. Hepatic cellular function may be compromised, especially if associated with other comorbidities.

## Indications

### Prevention of Atelectasis

General anesthesia causes a reduction in the FRC as a result of increased intra-abdominal pressure, loss of inspiratory muscle tone, and a change in thoracic blood volume. As a result, it is associated with postoperative atelectasis with subsequent hypoxemia as well as impaired clearance of secretions, both of which may predispose patients to pneumonia. By increasing FRC and preventing derecruitment of alveoli, PEEP may serve as a protective maneuver to avoid these adverse outcomes. This may be especially true of patients at higher risk for atelectasis including obese patients and those undergoing abdominal laparoscopy.

### ALI/ARDS

Patients with acute lung injury (ALI) or acute respiratory distress syndrome (ARDS) are by definition severely hypoxemic and nearly all require invasive mechanical ventilation. However, mechanical ventilation by itself can further injure damaged cells if used inappropriately. With the goal of minimizing any additional damage while maintaining adequate gas exchange, the ARDSnet protocol was created. Central to this protocol is the use of low tidal volumes, plateau pressure limitations, permissive hypercapnia, and PEEP. While the ideal amount of PEEP is specific to each patient, generally PEEP is initiated at 5 cm $H_2O$ and gradually increased to allow optimal arterial oxygenation while minimizing adverse effects.

### Cardiogenic Pulmonary Edema

Although PEEP doesn't decreases total extravascular lung water, studies suggest that it does redistribute extravascular lung water from the interstitial space between alveoli and endothelial cells toward peribronchial and perihilar areas. This redistribution can potentially improve arterial oxygenation.

## Contraindications

It is important to remember that PEEP is not a benign therapy and may be associated with adverse hemodynamic consequences which outweigh any gains in arterial oxygenation. Use in patients who are profoundly hypotensive from volume depletion or those that are dependent on cardiac preload to maintain output (i.e., cardiac tamponade) would be poorly tolerated because of the decrease in venous return associated with adding PEEP. Likewise, patient's with pre-existing right heart failure may experience worsening of symptoms because of the increased pulmonary vascular resistance and increased right ventricular afterload. Other contraindications include use in patients

with a pneumothorax as addition of positive pressure ventilation will worsen the pneumothorax and eventually result in hemodynamic collapse if the pressure is not relieved by chest tube placement. In patients with unilateral/focal lung disease (i.e., severe pneumonia), PEEP may hyperinflate the "good" lung, resulting in increased vascular resistance and worsening ventilation–perfusion mismatch. Lastly, as discussed above, the use of PEEP in patients with increased ICP should be deployed cautiously because of the potential for decreased perfusion pressure.

## Treatment of Auto-PEEP

In patients who develop auto-PEEP (intrinsic PEEP), there is inadequate time for exhalation and the next ventilator breath "stacks" on the previous breath. Without treatment, this can lead to cardiovascular collapse for the same physiologic reasons as those of extrinsic PEEP. After recognition, auto-PEEP can be treated by minimizing the I:E ratio (increasing expiratory time), aggressive bronchodilator therapy, and increasing the level of sedation in order to improve ventilator synchrony. In some specific cases (i.e., COPD), judicious application of extrinsic PEEP will counter intrinsic PEEP and decrease the work of breathing however this should be used cautiously because excessive extrinsic PEEP may limit expiratory flow and worsen hyperinflation.

## Ongoing Debate

While the benefits of using lung-protective strategies (combination of low tidal volumes, PEEP, and recruitment maneuvers) to improve oxygenation in pathologic lung states (i.e., ARDS) have been well documented, much less data exist regarding such a strategy in otherwise healthy patients. Because the use of PEEP is not a benign mode of therapy and can lead to serious hemodynamic consequences (as detailed above), controversy exists regarding which patients should receive such therapy intraoperatively. To address this question, a recent study by Futier et al. suggest that applying lung-protective strategies to moderate-to-high risk patients undergoing major abdominal surgery led to a significant decrease in postoperative pulmonary complications. Despite this provocative data, further studies are still needed to determine the ideal approach for intraoperative ventilation.

### TAKE HOME POINTS

- There are two types of PEEP; extrinsic (applied) PEEP and intrinsic (auto) PEEP.
- PEEP improves arterial oxygenation ($PaO_2$) by increasing FRC, recruiting partially collapsed alveoli, increasing lung compliance, and decreasing the overall work of breathing.

- PEEP has negative effects on the cardiovascular system including decreased venous return, decreased biventricular preload, and subsequently decreased cardiac output.
- Indications for PEEP include prevention/treatment of atelectasis, ALI/ARDS, and cardiogenic pulmonary edema.
- Contraindications for PEEP may include hypotension, hypovolemia, cardiac tamponade, pre-existing right heart failure, unilateral/focal pulmonary disease, tension pneumothorax, and increased ICP.
- Techniques to reduce intrinsic (auto) PEEP include bronchodilator therapy, increasing sedation, minimizing the I:E ratio, and in certain circumstances the use of extrinsic PEEP.
- While some recent data suggest that prophylactic use of lung-protective strategies (lower tidal volume, PEEP, and recruitment maneuvers) are associated with improved postoperative outcomes, further studies are needed to determine the ideal approach for intraoperative ventilation.

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15

# This Is No Time for Wishful Thinking: Always Troubleshoot an Increase in Peak Airway Pressure

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Occasionally, the anesthesiologist needs to troubleshoot elevated peak airway pressure in an intubated patient. Although each patient has a different baseline peak airway pressure, the anesthesiologist must investigate possible causes of a sudden increase in ventilating pressure (Box 15.1). For the most part, these pressure increases can be attributed to problems related to the patient, to airway/ventilation equipment, or even to positioning of surgical staff and equipment.

## Consequences of Elevated Ventilatory Pressure

Any sudden increase in peak airway pressures requires immediate attention. Barotrauma (trauma resulting from high peak pressure) or volutrauma (trauma to the lungs resulting from overstretched alveoli caused by increased tidal volume) can result from prolonged positive-pressure ventilation at high pressures and/or unrestricted lung expansions. Overstretch of alveoli may cause disruption of the alveolar–capillary membrane, thereby causing an increase in pulmonary vascular permeability and pulmonary edema. High peak inspiratory pressure (PIP) may also cause pneumothorax and pneumomediastinum. As a consequence, an acute respiratory distress syndrome–like picture, referred to as ventilator-induced lung injury, may develop. To prevent ventilator-induced lung injury, excessive PIP should be avoided and alveolar plateau pressures should be maintained below 25 cm $H_2O$, especially during prolonged ventilation in patients who are at increased risk for developing these injuries (vascular, cardiac, and thoracic operations, patients with preexisting lung disease).

In addition to injuring lungs, high airway pressures may also affect hemodynamics. If excessive positive end-expiratory pressure (PEEP) is used, or if auto-PEEP is generated by breath stacking, cardiac output may be adversely affected through the increase in intrathoracic pressure, which can impede venous return to the right ventricle.

In addition, compression of pulmonary vessels may increase right ventricular afterload, which in turn decreases right ventricular stroke volume and causes right ventricular dilatation. This subsequently shifts the interventricular septum toward the left ventricle, further reducing left ventricular preload and stroke volume. If breath stacking is prolonged and severe, cardiovascular collapse may ensue, typically appearing as pulseless electrical activity.

**Box 15.1 ■ Causes of Elevated Peak Inspiratory Pressure (PIP)**

Equipment failure

Depressing oxygen flush button during inspiratory phase of mechanical ventilation

Cough/light anesthesia

Bronchospasm

Mechanical obstruction of endotracheal tube or airway

Abdominal insufflation for laparoscopic procedures

Trendelenburg position

Decreased chest wall compliance (drugs, obesity, chest straps)

Tension pneumothorax

Auto-PEEP

## Airway/Ventilation Equipment Problems

One of the most important strategies in preventing high airway pressure–induced lung injury is to thoroughly check the anesthesia machine and breathing circuit system (including inspiratory and expiratory valves) before each use. In this way, mechanical problems can be remedied early. However, the fact that the machine was checked does not rule it out as the source of a sudden problem. Some examples include a suddenly stuck manual PEEP valve, a PEEP valve placed incorrectly into the inspiratory limb of the breathing circuit (this rarely happens because contemporary anesthesia machines have a built-in PEEP valve), a stuck expiratory valve causing breath stacking, or a faulty pressure-relief (pop-off) valve during spontaneous breathing. Other causes of high circuit pressures have been described, such as malfunctioning of ventilator relief and control valves, scavenger system blockage, or occlusion of the muffler on the ventilator.

Any of these can result in elevated peak airway pressures and should be considered in determining the underlying cause of elevated pressures in the breathing circuit. After initiation of mechanical ventilation, the pop-off valve should be set to the "open" position. With resumption of spontaneous breathing at the end of the case, if this valve were closed and this remained unnoticed, high pressure (50 to 60 mm Hg) could develop in the breathing circuit and in the patient's lungs. This high pressure can be further aggravated by flushing bypass oxygen into the system. The same applies when, after the circuit has been disconnected and then reconnected to a tracheal tube, in order to fill the ventilator bellows, an anesthesiologist pushes the oxygen bypass button simultaneously with mechanical inspiration. During this maneuver, all gas delivered to the circuit is directed toward the patient's lungs, potentially causing barotrauma.

## Patient-Related Problems

### Cough/Light Anesthesia

One of the most clinically apparent causes of increased peak airway pressures in the practice of anesthesia is the patient coughing or bucking during light anesthesia. This is often resolved simply by increasing the depth of anesthesia by increasing inspiratory concentration of inhaled anesthetic, or administration of intravenous (IV) anesthetic (e.g., propofol, lidocaine) or IV opioid.

### Bronchospasm/Wheezing

Bronchospasm is a frequent cause of increased PIP. Auscultation of the lung fields can confirm this diagnosis if expiratory wheezes are present. Extreme cases of bronchospasm may be associated with no wheezing because air may not be moving. Bronchospasm can also be a part of intraoperative allergic reactions (anaphylactic or anaphylactoid reactions), but rash, tachycardia, and hypotension frequently will be associated. Treatment with albuterol, epinephrine, or diphenhydramine, deepening of inhalational anesthesia, and discontinuing or avoiding the offending agent can help relieve this type of bronchospasm. Reviewing the patient's allergies and avoiding those drugs and other similar compounds is the easiest way to prevent such anaphylactic reactions.

### Mechanical Airway Obstruction

Intraoperative wheezing with high PIP can also be caused by endotracheal tube narrowing (tube kinking, the patient biting the tube, overinflation of the tube cuff causing occlusion of the lumen) or increased airway secretions. Even a dislodged nasal turbinate has been described to occlude the endotracheal tube, causing inability to ventilate the lungs. Passing a flexible suction catheter through the endotracheal tube can

help confirm patency and, in the case of secretions, can help remedy the problem. However, direct visualization with a fiberoptic bronchoscope is the "gold standard" for determining the definitive cause of endotracheal tube obstruction. Secretions distal in the tracheobronchial tree or foreign-body aspiration can produce similar signs and are unlikely to be identified by the suction catheter test, requiring further exploration with fiberoptic bronchoscopy or possibly chest radiography in the case of a foreign body. External compression of the airway by surgical equipment or personnel also can cause an acute increase in PIP, and if recognized, can be easily remedied by communicating the problem and possible solutions to the surgical staff.

## Positioning/Surgical Factors

When a patient is placed in a steep Trendelenburg position, increased peak airway pressures may be encountered, especially if the patient is morbidly obese. This position causes the abdominal contents and overlying chest structures (large breast) to shift in the cranial direction. This shift causes an increased mass effect on the diaphragm and chest wall, which will increase airway pressures and may result in difficulty achieving adequate ventilation. In addition, an endotracheal tube sited in the distal part of the trachea while the patient is supine may migrate toward the carina in the Trendelenburg position and potentially result in endobronchial intubation. This situation would yield an increased peak airway pressure; moreover, a sudden concomitant decrease in end-tidal $CO_2$ concentration on capnography may be suggestive of endobronchial migration of the tracheal tube. If endobronchial intubation is suspected, one should begin with auscultation for bilateral breath sounds. If unilateral breath sounds are detected, incrementally withdrawing the endotracheal tube with repeat auscultation for return of breath sounds is recommended. The anesthesiologist should always observe the tracheal tube depth markings (labeled in centimeters) to prevent unintentional tracheal extubation, which in a patient with a difficult airway can be particularly catastrophic. Observing that the tracheal tube is inserted to 21 cm in females and 22 to 23 cm in males at incisors would suggest adequate endotracheal tube placement.

## Decreased Pulmonary and Chest Wall Compliance

A gradual decrease in pulmonary compliance with an increase in PIP during massive fluid administrations may be indicative of pulmonary edema. Furthermore, continuous monotonous ventilation without PEEP may result in gradual atelectasis, which will increase the overall stiffness of the lungs. Occasional intraoperative performance of the vital capacity (recruitment) maneuver may be therapeutic in these situations. Rarely, decreased chest wall compliance can be encountered with the use of opioids (chest wall rigidity). Centrally mediated muscle contraction can be seen usually after quick and

large boluses of lipophilic opioids fentanyl, sufentanil, and alfentanil. Chest wall rigidity caused by opioids can be severe enough to impede ventilation. Fortunately, treatment with neuromuscular blockade is an effective method for reversing chest wall rigidity and allowing adequate ventilation. A similar situation with decreased chest wall compliance may occur if additional force is applied to the chest (e.g., surgical equipment, surgical staff leaning on the chest).

## Acute Decreases in Lung Parenchymal Volume

Anything that increases the intraabdominal volume (e.g., insufflation of the abdomen for laparoscopic surgery, ascites, abdominal packing) may also elevate PIP. Obesity and placing the patient in the Trendelenburg position may exacerbate these effects, and may require movement or removal of retractors, decreasing the insufflation pressure for laparoscopy, and/or reducing the degree of Trendelenburg position of the patient to maintain adequate ventilation. Maintaining adequate ventilation in the setting of elevated $CO_2$ tension resulting from abdominal insufflation can be particularly difficult and requires good communication between the anesthesia and surgical teams.

Similarly, compression of the lung parenchyma by pleural effusion or tension pneumothorax can affect airway pressures. Evacuation of pleural fluid by needle aspiration is helpful but should be done before anesthesia and mechanical ventilation; even then, signs of pneumothorax must be excluded before mechanical ventilation is initiated. In the case of pneumothorax, even a simple pneumothorax can become a tension pneumothorax when positive-pressure ventilation is used. If a tension pneumothorax is suspected intraoperatively, immediate needle decompression is indicated. This is performed by inserting a 14-G over-the-needle catheter into the second intercostal space at the midclavicular line on the affected side. This will convert a tension pneumothorax to an open pneumothorax, buying time until a chest tube can be placed.

## Auto-PEEP

Patients with acute or chronic obstructive airway disease may develop breath stacking or auto-PEEP. This phenomenon occurs when the expiratory phase of the breath is not long enough to allow full expiration of the inspired tidal volume. Each subsequent breath then adds incrementally to the intrathoracic volume and pressure, and if it proceeds unchecked, can result in barotrauma, decreased venous return, and tension pneumothorax. Auto-PEEP is typically generated when the expiratory time is too short, secondary to a rapid respiratory rate, an inspiratory:expiratory (I:E) ratio that is not adjusted to include additional expiratory time, or both. If auto-PEEP is suspected, ventilator settings should attempt to reduce the respiratory rate and increase the

expiratory time via changing the I:E ratio while simultaneously diagnosing and treating the underlying cause of airway obstruction.

## Conclusion

Every anesthesiologist must be able to quickly troubleshoot increased ventilatory pressure during anesthesia. Ignoring it may result in severe consequences and induce serious injury to the patient's lungs.

### TAKE HOME POINTS

- A sudden increase in the peak airway pressure requires immediate investigation.
- Barotrauma is rare and may lead to pneumothorax.
- Volutrauma (prolonged ventilation with high plateau pressures leading to lung overdistension) can lead to ventilator-induced lung injury indistinguishable from adult respiratory distress syndrome.
- High airway pressure increases intrathoracic pressure, causes compression of pulmonary vasculature, and induces a decrease in venous return causing a decrease in ventricular output and therefore can adversely affect hemodynamics (hypotension and bradycardia).
- A thorough machine check does not eliminate the possibility of an intraoperative machine failure as the cause of high airway pressures.
- Consider patient-related problems as well, including bronchospasm, decreases in lung compliance (pulmonary edema), acute decreases in lung volume (atelectasis), or pneumothorax.
- Fiberoptic bronchoscopy is the gold standard to rule out an obstruction of the endotracheal tube as a source of increased airway pressures.

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# The Key to the Smooth and Skilled Placement and Use of Double-Lumen Endotracheal Tubes Is to Take It One Step at a Time

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## Introduction

The use of double-lumen endotracheal tubes (DLTs) is standard practice in thoracic and other surgical procedures requiring one-lung ventilation (OLV), as well as in life-threatening conditions requiring lung isolation, such as hemoptysis. Although the techniques for accurate placement and ventilation with DLTs are more complex than for placement of a standard endotracheal tube, practitioners should be no more intimidated by them than by any other (slightly advanced) airway procedure. The trick to the placement and use of a DLT is to take it step by step. Remember that appropriate caution in placing DLTs is always warranted (never force "the square peg in a round hole"), but no more than in any other area of anesthetic practice.

## Sizing of Double-Lumen Endotracheal Tubes

DLTs are designed to ventilate one lung while isolating the contralateral side. Although there are design differences depending on the manufacturer, all DLTs consist of a tracheal lumen and an endobronchial lumen. Sizes of DLTs vary from 26F to 41F (1F equals 1/3 mm and is a measurement of diameter). A 39F DLT is equivalent to a 9.5-mm internal-diameter endotracheal tube. Choosing the "proper size" has been a topic of many investigations, including the use of chest radiographs and computerized tomography (CT) scans to measure tracheal and bronchial diameters. No one method has proven to be an absolute predictor of the "optimal" size of DLT; or, in other words, one should choose the size DLT that results in the fewest minor and major complications for any given patient, but still functions reliably in the intraoperative period. Traumatic airway injuries are common with DLTs, with a high incidence of hoarseness and sore throat, and presumably an oversized tube will contribute to this

unnecessarily. However, undersizing a DLT can result in poor lung isolation from malposition and/or intraoperative migration.

## Placement of Double-Lumen Endotracheal Tubes

The typical method of placing a left DLT is to use direct laryngoscopy to pass the bronchial tip through the vocal cords, remove the stylet, and then advance the tube until the "double" portion (the thicker portion with two lumens) passes through the larynx. At this point, for proper placement in the left bronchus, a "blind" or fiber-optic technique may be used. In the "blind" technique, the bronchial cuff is placed past the vocal cords and the stylet is removed. The tube is then rotated counter-clockwise and the tube is advanced until it meets resistance (approximately 28 to 30 cm at the teeth), suggesting placement in the left mainstem bronchus. Using the fiber-optic method, the bronchial tip is placed past the vocal cords, the scope is placed through the bronchial lumen and driven into the left mainstem bronchus, and the tube is advanced over the scope into the left mainstem bronchus.

There are advantages and disadvantages to each technique for initial placement of DLTs. The fiber-optic scope technique is favored by some senior practitioners and is often described as the technique of choice. However, a fiber-optic scope may not be available or may not be helpful in situations of significant hemorrhage or secretions, and one must then rely on clinical skills for proper positioning.

The "blind" technique allows for rapid placement without the need for excess equipment other than a stethoscope for auscultation to confirm correct placement. Unfortunately, malposition requiring further manipulation has been reported as from 30% to 78%. Leaving the stylet in place for the entire "blind" placement has demonstrated improved success, although the potential risk for airway trauma may outweigh this benefit. An additional technique that has been reported to increase success involves insufflating 2 mL of air into the bronchial cuff after placement, withdrawing while holding the pilot balloon until it collapsed, deflating the bronchial cuff, and advancing 1.5 cm. Proper placement occurred in 26 of the 29 left-sided DLT attempts using this method. One major disadvantage with the "blind" method, beyond lower success rates, is the inability to visualize anatomic problems. An example is thoracic aortic aneurysms, which can compress the left main bronchus, impairing placement and potentially leading to aneurysm rupture by "blind" DLT placement.

Left-sided double-lumen placement can be confirmed by auscultation or by fiber-optic visualization. With proper techniques, clinical confirmation can be performed successfully with a stethoscope. First, inflate the tracheal cuff and listen for bilateral breath sounds. Clamp the circuit tubing leading to the tracheal lumen, open the tracheal vent, and listen for a leak on the tracheal side. Inflate the bronchial cuff until the leak

disappears, which usually requires less than 2 mL of air, and never more than 3 mL. Isolation is confirmed by the loss of breath sounds on the tracheal side and preserved sounds on the bronchial side. Bilateral breath sounds should return after the clamp is removed and the vent is closed.

If the auscultation technique does not confirm placement, fiber-optic confirmation is warranted, if available. One should always visualize the right upper-lobe bronchus through the tracheal lumen with the bronchoscope, to confirm that the bronchial portion has been accurately placed in the left mainstem bronchus, and not mistakenly on the right side. When visualizing the carina and the bronchi through the tracheal lumen, the bronchial cuff should be barely seen at the entrance to the left mainstem bronchus, or, with BronchCath Mallinckrodt DLTs, a black line which marks 4 cm from the distal tip of the bronchial lumen should be evident just proximal to the opening of the bronchus. Because the left main bronchus is longer than 5 cm in both men and women, this should provide ideal placement.

## Bronchial Cuff Inflation

Insufflation of the bronchial cuff is an important part of final placement of the DLT. If the patient is to be placed in the lateral decubitus position, it may be best to insufflate the bronchial cuff after final positioning to prevent the DLT from being displaced as well as to avoid overinflating the cuff. There are alternative methods to auscultation to determine the minimal amount of air needed for lung isolation to prevent mucosal ischemia. While ventilating, 0.5 mL of air at a time (not to exceed 3 mL) is injected into the bronchial cuff, a bare hand or arm is placed over the open bronchial vent, and the bronchial side is clamped. The leak will disappear when isolation is achieved. Another technique involves placing a nasogastric tube tip in the bronchial lumen and the other end in a bottle of saline while slowly injecting air into the cuff until bubbles are no longer apparent. **Always remember to deflate the bronchial cuff when lung isolation is no longer necessary.**

## Mechanical Ventilation

The choice of the appropriate tidal volume (TV) for OLV is an important area of evolving practice. Recent evidence suggests that lower lung volumes during OLV (5 mL/kg) with positive end-expiratory pressure (PEEP) during esophagectomy, a "protective ventilation strategy" similar to that used in acute lung injury (ALI) patients, resulted in decreased inflammatory response, improved lung function, and earlier extubation. In patients with obstructive lung disease, there is the possibility for auto-PEEP with larger TVs if adequate time is not allowed for exhalation. Maintaining peak pressures >40 cm $H_2O$ and higher TVs led to a higher incidence of postpneumonectomy

ALI and respiratory failure. These considerations make it clear that the higher traditional TVs of 9 to 12 mL/kg should be reduced during OLV.

The use of PEEP is sometimes considered controversial because of the concern that capillary compression will cause shunting of blood flow away from the ventilated lung. However, given the prevalence of atelectasis contributing to hypoxemia and the body of data showing the protective role of PEEP in reducing ventilator-associated lung injury, the use of moderate PEEP (4 to 8 cm $H_2O$) is recommended. In general, if a manual recruitment maneuver improves oxygenation, then PEEP will help maintain that effect. Periodic recruitment maneuvers may thereafter be necessary to preserve the improved oxygenation. Attention should be paid to cardiovascular changes during recruitment, as brief hypotension is common.

**Table 16.1 ■ Differential Diagnosis of Hypoxemia During OLV**

| Diagnosis | Clinical Findings |
|---|---|
| **Mechanical** | |
| Mechanical disconnect | Abrupt loss of $EtCO_2$ and minute ventilation (MV) |
| Mucus plug | Increasing peak airway pressure |
| Hypoventilation | Low MV or loss of delivered tidal volume |
| **Pulmonary** | |
| Atelectasis | Improvement after recruitment maneuver |
| Bronchospasm | Abrupt rise in peak airway pressures. Improvement with beta-agonist |
| Pneumothorax | High airway pressures, reduced breath sounds, hypotension |
| Pulmonary embolus | Abrupt loss of $EtCO_2$. Tachycardia. Increase right heart pressures |
| Pulmonary edema | Increased, pink, frothy secretions in DLT |
| Aspiration | Abrupt rise in peak airway pressures. Evidence of foreign material on bronchoscopy |
| **Other** | |
| Low cardiac output | Low $EtCO_2$ signifying V/Q mismatching and |

| | |
|---|---|
| Loss of hypoxic vasoconstriction | increased dead space<br>Improvement with use of total intravenous anesthesia |

## Hypoxia During One-Lung Ventilation

Hypoxia during OLV is common with an average rate of 10%. This figure can be higher depending on patient population and positioning. The differential diagnosis for hypoxia during OLV is large (Table 16.1) and requires diligence for quick diagnosis and appropriate management. If the onset of hypoxia is acute, the surgical team should be notified and the nondependent lung should be inflated to allow improved oxygenation while the true cause is determined. If onset of hypoxia is more gradual and the patient remains stable, the first step is to ensure the integrity of the breathing circuit and delivery of adequate TVs. Next, the $FiO_2$ should be increased to 1.0 if this is not already the case, followed by assessment with bronchoscopy to confirm the DLT position and possibly clear secretions. After confirming ETT placement, recruit the dependent lung with 30 cm $H_2O$ for 30 seconds. PEEP of 10 cm $H_2O$ should be administered to the dependent (ventilated) lung. Further maneuvers involve continuous positive end-expiratory pressure (CPAP) of 10 cm $H_2O$ to the nondependent lung. Furthermore, total intravenous anesthesia can be an option to help improve hypoxic vasoconstriction which is blunted by volatile anesthetic gases, although no improvements in outcomes have been shown when these two anesthesia modalities have been compared. If hypoxia is refractory, help should be summoned and an alternative diagnosis should be sought (Table 16.1). In addition, for profound refractory hypoxemia, one should alert the surgeon and consider switching back to bilateral lung ventilation.

### TAKE HOME POINTS

- Double-lumen endotracheal tubes provide a simple means for one-lung ventilation and lung isolation.
- The ability to properly place and confirm DLT position needs to be part of every anesthesia practitioner's repertoire.
- Seek out these cases and take the airway management one step at a time: "Number one, have we intubated the trachea? Number two, what information do we have that the bronchial lumen is where we want it?" and then proceed down the algorithm.
- The editor recommends that junior practitioners take a try at confirming placement by auscultation before using the fiber-optic method. It is a great way to really get a

sense of how the DLT will function later in the case.

- If the DLT is "not working," remember that unless you have turned the whole thing 180 degrees, it is either in too far or not in far enough. If you cannot figure out which is the case, consider withdrawing the bronchial lumen into the trachea and starting over. Early use of bronchoscopy can provide essential information quickly.
- Once placement has been confirmed, avoid taping it to what will be the dependent side of the face, and do not "overtape" it. Occasionally, the DLT will have to be moved several millimeters during the case, and many practitioners have had to struggle with peeling a wad of tape off the side of the patient's face that has been positioned in the foam head ring.
- With careful placement and a lung-protective strategy with lower TVs, and the use of PEEP, proper use of DLTs may provide postoperative benefits and better surgical outcomes.
- Hypoxia is common during OLV and the differential diagnosis is vast. By taking a standardized, methodical approach one can quickly determine and treat the underlying cause.

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# Avoid Common Airway and Ventilation Errors in Morbidly Obese Patients

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## Introduction

Over the past 20 years, the incidence of obesity has increased significantly in both adults and children. Obesity is defined as a body mass index (BMI) of 30 kg/m$^2$ or greater. The latest data from the U.S. National Center for Health Statistics show that 35% of adults aged 20 years and above—more than 60 million people—are obese, higher from 22% in the 1988 to 1994 data. This increase is not limited to adults; the percentage of young people who are overweight has more than tripled since 1980.

For an anesthesiologist, this means that greater numbers of morbidly obese patients will require care. Concerns with regard to morbid obesity include:

- Airway and ventilatory management
- Drug dosing (ideal vs. total body weight)
- Injuries related to positioning while anesthetized
- Perioperative complication related to more frequently associated comorbidities (coronary artery disease, hypertension, pulmonary hypertension, cor pulmonale)
- Glucose control (metabolic syndrome)
- Reactive airway/asthma
- Obstructive sleep apnea (OSA)/sleep-disordered breathing-related complications

This chapter focuses on airway management and ventilatory issues in morbidly obese patients.

## Obstructive Sleep Apnea

OSA is present in approximately 70% of morbidly obese patients undergoing bariatric surgery. Patients with OSA are more sensitive to respiratory depression from anesthetics, opioids, and sedatives. Thus, they are at an increased risk of airway obstruction or apnea postoperatively, which can lead to hypercarbic respiratory arrest

or failure. Timely intervention with noninvasive ventilation and use of monitored settings may reduce the rate of OSA-related complications. Specifically, if the patient has a prescribed level of continuous or biphasic positive airway pressure preoperatively, these treatments should be initiated postoperatively, ideally immediately after tracheal extubation.

Frequent night arousals are associated with interrupted rapid eye movement (REM) sleep (resulting in daytime somnolence) and catecholamine surges (resulting in systemic and pulmonary hypertension), while intermittent hypoxemia may contribute to polycythemia. More severe forms can result in persistent hypercarbia with development of pulmonary hypertension and/or cor pulmonale. These patients may have a higher incidence of postoperative complications due to respiratory issues as well as due to the presence of obesity-associated comorbidities.

The diagnosis of OSA is made with the help of overnight polysomnography which generates the apnea–hypopnea index (AHI). The AHI reports the number of apneic and hypopneic episodes per hour. Apnea and hypopnea are defined as:

. Apnea – no respiratory effort for 10 seconds or more.
. Hypopnea – a significant reduction of airflow by 50% or causing an arousal from REM sleep or decrease in oxyhemoglobin saturation.

The severity of OSA is quantified using the AHI with categories defined as none (≤4), mild (5 to 15), moderate (16 to 30), and severe (≥31). This classification represents a slight modification (to avoid overlap between categories) of the American Academy of Sleep Medicine criteria.

A significant number of surgical patients have undiagnosed OSA, which may contribute to the development of respiratory complications. Unfortunately, polysomnography is expensive, time consuming, and of limited availability; thus it is not feasible for all patients or even for those at high risk of OSA.

Several screening assessment tools were developed and are used to preoperatively screen patients at risk for OSA. The most commonly used tool is the STOP-BANG questionnaire which is based on eight factors: **S**noring, daytime **T**iredness, **O**bserved apneas, and high blood **P**ressure (STOP); and **B**MI >35 kg/m$^2$, **A**ge >50 years, **N**eck circumference >40 cm, and male **G**ender (BANG). Three positive responses indicated a high risk for OSA. It has been validated with polysomnography and has a sensitivity ranging from 83.6% to 100%. Another study found that the STOP-BANG model correlates with no, mild, moderate, and severe OSA on polysomnography. Yet another is the sleep apnea clinical score (SACS). Four variables (neck circumference, hypertension, habitual snoring, and nocturnal gasping or choking) generate a score ranging from 0 to 100. Validated by polysomnography, a score greater than 15 has a 25% to 50% likelihood of an AHI >10. A third commonly used screening tool is the

Berlin questionnaire with 10 variables (including nonrestorative sleep, sleepiness while driving, periods of apnea during sleep, BMI, and hypertension). When correlated with home polysomnography, the sensitivity and specificity for an AHI >5 is 86% and 77%; for AHI >15, 54% and 97%.

## Associated Conditions

Morbidly obese patients are more likely to have metabolic syndrome (diabetes, hypertension and abnormal cholesterol and/or, elevated triglycerides). These patients, when compared to non-OSA patients, are more likely to have myocardial infarction, stroke, and congestive heart failure. Diastolic dysfunction may contribute to congestive heart failure perioperatively. The combination of cardiac and pulmonary disease can result in cor pulmonale with pulmonary hypertension. Polycythemia may occur due to recurrent hypoxemia. These patients may also develop obesity-hypoventilation syndrome. Metabolic syndrome and decreased mobility can contribute to development of DVT and pulmonary embolism. Cor pulmonale with hepatic congestion may further contribute to liver dysfunction. Independently, morbidly obese patients can also have hepatosteatosis (the most serious stage of hepatosteatosis is cirrhosis) with possible liver dysfunction and abnormal drug metabolism.

## Physiologic Alterations

The respiratory system changes that occur in obese patients with OSA are of keen interest for anesthesiologists. Redundant oral and pharyngeal tissue can reduce the airway diameter and may contribute to difficulties in mask ventilation as well as tracheal intubation. They may also have restrictive lung disease due to increased body fat over the chest wall (decreased chest wall compliance) as well as compression by abdominal fat. All these factors lead to significant reduction in functional residual capacity (FRC), which results in lower oxygen reserve during periods of apnea during tracheal intubation and extubation. A lower FRC, larger alveolar-to-arterial oxygen gradient, and a higher tendency for hypoventilation during sedation may result in precipitous oxyhemoglobin desaturation during monitored anesthesia care and induction of general anesthesia. Oxygen consumption and carbon dioxide production is higher, further contributing to development of hypoxemia and respiratory acidosis.

## Establishing the Airway

Several studies have compared the difficulties in intubating the trachea in morbidly obese and normal-weight patients. Neither BMI nor OSA has been shown to be independent predictors of difficult tracheal intubation. Neck circumference and

Mallampati score have been shown to be indicators of a difficult airway: neck circumference of 40 cm was associated with a 5% incidence of a difficult airway, and a 60-cm circumference was associated with a 35% incidence of difficulty. Intubation difficulty is associated with increasing Mallampati class, decreased thyromental distance (<6.5 cm), and restricted jaw mobility. The availability of additional personnel when establishing the airway in morbidly obese patients cannot be overstated.

Mask ventilation may be more difficult in this patient population. This, together with the physiologic respiratory changes associated with obesity, may contribute to faster development of hypoxemia in clinical setting and forces providers to move more hastily during airway management. Therefore, the anesthesiologist must be confident in managing the airway in these patients; otherwise, awake fiber-optic intubation should be considered as a safe alternative.

Aligning the patient's sternum and ear in a horizontal line by "ramping" with blankets under the upper body will assist in oxygenation and placement of the endotracheal tube. Positioning in the head-up position (25 to 30 degrees) will improve diaphragmatic movement, increase FRC, and delay development of hypoxemia.

The use of CPAP for preoxygenation during induction at 10 cm $H_2O$ has been shown to decrease nonhypoxemic apnea. Nasopharyngeal supplemental oxygen with continuous positive airway pressure (CPAP) may assist in maintaining adequate oxygenation during airway manipulation. Upper airway collapse (mouth, pharynx) may compromise ventilation and visualization of glottic opening; thus preservation of spontaneous ventilation during management of a difficult airway must be considered.

In morbidly obese patients with a high Mallampati score or large neck circumference, awake fiber-optic intubation should be considered and readily available; however, other possibilities include performing the tracheal intubation with rigid intubating devices designed for a "difficult airway," such as a videolaryngoscope (VL). Awake intubation success with a VL has been reported in bariatric surgical patients. In one study comparing ventilation during surgery in moderately obese patients with an endotracheal tube versus a laryngeal mask airway (LMA), postoperative pulmonary function was significantly better in the LMA group.

If endotracheal intubation is difficult and/or mask ventilation is suboptimal, alternative strategies must be available. An LMA, ideally an intubating LMA, can be used to establish ventilation and maintain oxygenation and then establish endotracheal intubation through the device. Cricothyroidotomy or tracheostomy are the last options, although these can be difficult in obese patients because of lack of recognizable landmarks, excessive tissue, and the ability to establish an airway in a timely manner if the patient is unstable. Use of the LMA in morbidly obese patients is plagued by the fear of gastric aspiration. However, no reports have noted increased pulmonary aspiration of

gastric contents in obese patients, and contrary to belief, retrieval of gastric contents in these patients revealed low residuals. When placed electively after induction of anesthesia in morbidly obese patients, the LMA is an effective airway tool.

## Ventilation After the Airway is Established

Compared to normal-weight patients, morbidly obese supine patients have lower FRC which leads to an increased alveolar-to-arterial oxygen gradient (lower arterial $PaO_2$) and this contributes to faster development of hypoxemia with hypoventilation or while apneic during anesthetic induction. Intraoperatively, a ventilation strategy that uses a larger tidal volume will not improve oxygenation, and data are emerging that high tidal volumes may actually worsen postoperative outcome as a result of lung injury. Whichever mode of ventilation is used, goal should be to maintain alveolar plateau pressures $\leq$25 cm $H_2O$. This task may be difficult to achieve in the presence of pneumoperitoneum and if the patient is positioned in reverse Trendelenburg posture. Isolated effects (without recruitment) of positive end-expiratory pressure (PEEP) of 10 cm $H_2O$ used intraoperatively only modestly improves oxygenation in morbidly obese anesthetized patients. High levels of PEEP can be deleterious, contributing to decreased cardiac output, worsening of oxygenation and ventilation, and may lead to lung injury (if associated with high plateau pressures). Recruitment maneuvers during the procedure at regular intervals (indicated by decrease in $SpO_2$) with minimum 40 cm $H_2O$ for 8 to 10 seconds (this time interval is the time needed to open the collapsed alveoli in "healthy lungs") may help to reverse atelectasis; this maneuver must be followed by sufficient levels of PEEP to keep the lungs open. The optimal levels of PEEP were not determined yet in morbidly obese patients, but 10 and 12 cm $H_2O$ of PEEP were not shown to be sufficient to prevent redevelopment of atelectasis. More recent data suggest that higher levels of PEEP do not prevent development of postoperative pulmonary complications after abdominal surgery in the general surgical population. Maintenance with an $FIO_2$ of 60% versus 100% may be advantageous because it does not contribute to the development of absorption atelectasis.

## Hazards of Tracheal Extubation

Tracheal extubation in the morbidly obese can be hazardous. Patient's lungs on emergence from anesthesia are more likely to be atelectatic; these patients exhibit high sensitivity to respiratory depressants, and even a small residual neuromuscular blockade may contribute to inability to maintain adequate ventilation. It is critical to have a plan established in the case of extubation failure.

A lung recruitment maneuver just prior to tracheal extubation and the early use of

noninvasive ventilation may assist in successful transition from tracheal intubation to unassisted spontaneous ventilation. There is some evidence that the early initiation of noninvasive ventilation in the morbidly obese after extubation resulted in a risk reduction in respiratory failure. If feasible during extubation, the patient should be in the head-up position to maximize FRC, full muscle strength must be achieved (neuromuscular blockers reversed), and patient should follow commands. A nonopioid analgesic plan may be developed to allow patients to cough deep breath and mobilize as soon as possible after surgery.

Once the patient's trachea is successfully extubated, a close observation must continue in the recovery room; hypercarbia can be insidious despite adequate oxygenation as assessed by the $SpO_2$ values (more so in patients with supplemental oxygen). In the presence of respiratory warning signs (apnea, hypoxemia, significant pain–sedation mismatch), consideration should be given to admission to a monitored setting postoperatively. In addition, the patient is still at risk for respiratory complications at days 3 to 5 due to sedating medications and REM rebound. Patients without the prior diagnosis that exhibit signs of OSA perioperatively should be advised to undergo a sleep study.

## TAKE HOME POINTS

- Respiratory system alteration in morbidly obese patients include low FRC (in supine body position, and even more after anesthetic induction agents are given), presence of redundant upper airway tissues, increased sensitivity to opioids and sedatives, and increase in alveolar arterial oxygen gradient at baseline pose increased risks during anesthesia induction and maintenance. The time to establish airway (achieve tracheal intubation—before hypoxemia ensues) is shorter in obese patients compared to normal-weight patients.
- Morbidly obese patients are at higher risk for airway compromise because of OSA; therefore, sedation should be gradual, and spontaneous breathing must be maintained and closely monitored.
- Tracheal intubation may be more difficult in morbidly obese patients. Therefore, careful assessment of the airway, precisely devised plan management that includes availability of alternative intubating strategies are mandatory.
- When establishing a known difficult airway in a morbidly obese patient, awake fiber-optic intubation must be considered as the technique of choice; however, different videolaryngoscopic techniques have been successfully used for intubation in these patients lately.
- Appropriate positioning in the reverse Trendelenburg position with a wedge placed below the shoulders and maximal "sniffing position" will facilitate visualization of

glottic opening during direct laryngoscopy for tracheal intubation and the maintenance of ventilation with mask will be easier.

- Application of PEEP at 10 cm $H_2O$ prior to and during induction may prolong normoxia during airway management.
- Extreme care must be taken during extubation.
- Patients must be carefully monitored in the recovery room with a well-developed plan should respiratory distress develop.

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# Anesthesia for Awake Intubations

Chauncey T. Jones, MD

Awake intubations are an integral component of known difficult airway management. It is a key component of the ASA Difficult Airway Algorithm. Operator experience in managing these airways is the most important variable to a safe outcome. Preparation of the patient and the airway are key components in achieving a successful awake intubation. Failure of an awake intubation in appropriately selected patients results in case cancellation or the need for invasive airway access.

Preparation of the patient involves discussion of what to expect and how the patient can help the process go smoothly and mild sedation, as respiratory status permits. However, sedation should not be to the point of airway obstruction or disinhibition of the patient.

A key component of procedural expertise is preparation of the airway for awake intubation with local and regional anesthesia techniques. The goal is to anesthetize the entire route that the intubation will take, whether nasal or oral. This course can be divided into nasal or oral cavities; nasopharyngeal, oropharyngeal, and hypopharyngeal regions of the pharynx; and subglottic regions which include the larynx and trachea. The innervation of these regions must be blocked for successful awake intubation.

## Innervation

The **nasal cavity** innervation is derived from two branches of the trigeminal nerve (V), ophthalmic (V1), and maxillary (V2). The anterior ethmoid nerve (from V1) innervates the anterior aspects of the nasal cavity and septum. Posterior nasal cavity and septum are innervated primarily by lateral posterior superior, lateral inferior posterior, and nasopalatine nerves of V2.

The **oral cavity** sensory innervation and muscles of mastication derive from the mandibular branch of trigeminal nerve (V3). Muscles of the tongue are supplied primarily by the hypoglossal nerve, CN XII. Its general sensory is from lingual nerve, a branch of V3 for the anterior 2/3 and by glossopharyngeal, CN IX for posterior 1/3. The hard and soft palate is innervated by greater and lesser palatine nerves respectively,

which are branches from V2.

Sensory innervation of the entire **pharynx and epiglottis** is supplied primarily by glossopharyngeal nerve, CN IX and motor nerve supply is from the vagus nerve, CN X.

Superior laryngeal nerve, derived from vagus, CN X, supplies sensory to the **larynx** above the true vocal cords as well as to the cricothyroid muscle. The recurrent laryngeal nerve, also from vagus, CN X supplies all other muscles of the larynx and sensation at the level of vocal cords and below. Recurrent laryngeal nerve also supplies sensory and motor nerves to the **trachea**.

**Table 18.1 ■ Commonly Used Local Anesthetics for Airway Blocks**

| Drug | Clinical Use | Onset | Duration (minutes) | Maximum Dose |
|---|---|---|---|---|
| Cocaine | Topical (nasal) | Slow | 30–60 | 1.5 mg/kg |
| Benzocaine | Topical | Fast | 5–10 | 200 mg |
| Lidocaine | Topical/nerve blocks | Medium/fast | 30–60/60–180 | 4 mg/kg no epi<br>7 mg/kg with epi |

Several protective reflexes can be elicited with airway manipulation, which include gag, glottic closure (laryngospasm), and cough. These reflexes can be blocked by either their afferent (sensory) and/or efferent (motor) components. Input for the gag reflex is the glossopharyngeal nerve, CN IX and output is vagus nerve, CN X. Fibers for glottic closure reflex are superior laryngeal for afferent and both superior and recurrent laryngeal for efferent. Other reflexes that may also be encountered are bronchospasm reflex, secretory reflex, vomiting reflex, and cardiovascular reflex.

## Anesthetization of the Airway

Anesthetization of the airway for awake intubation can be achieved by a number of techniques and can be catered to the patient, the operator preference, and availability of supplies. These often include a mixture of topicalization and nerve blocks (Table 18.1). Topicalization methods include direct application of lidocaine or viscous lidocaine, aerosol spray, atomization, or nebulization. Common nerve blocks include glossopharyngeal, superior laryngeal, and translaryngeal nerves. Other blocks could be performed, such as maxillary and mandibular nerve blocks. However, these are more

invasive with a lower risk/benefit ratio and their relevant terminal nerves can easily be blocked topically.

## Nasal Cavity/Nasopharynx

Anesthetizing the nasal cavity can be achieved with topical local anesthetics (Table 18.2). Lidocaine, along with a vasoconstrictor, is most commonly used. Afrin may be used as a vasoconstrictor to decrease the incidence or severity of epistaxis. Phenylephrine can also be added to lidocaine for the same effect. A 3:1 combination of 4% lidocaine with 1% phenylephrine will yield at 3%/0.25% solution that can be applied by inserting a cotton-tip applicator. Alternatively, 2% viscous lidocaine can be mixed with phenylephrine to make a similar suspension and applied with a cotton-tip applicator as well as serially increasing sizes of nasal airways. This not only anesthetizes and vasoconstricts the nasal cavity, but also lubricates and dilates it to the desired sized ETT, usually 7.0. The nasal trumpet usually extends further into the nasopharynx and provides better nasopharyngeal block than the cotton-tip applicator. In addition, a slip-tip syringe (with or without an angiocatheter) can be used to inject several milliliters of 2% to 4% lidocaine through the nasal trumpet to further anesthetize the nasopharynx, oropharynx, and hypopharynx as the solution travels down the pharynx.

**Table 18.2 ■ Commonly Used Topical Methods for Airway Blocks**

| Method | Local Anesthetic | Notes |
|---|---|---|
| Nasal Topical | 1. 4% Cocaine<br>2. 2–4% Lidocaine or Viscous Lidocaine with 1% phenylephrine | Cocaine and phenylephrine cause vasoconstriction and decreased chance of epistaxis. Afrin may also be used. |
| Aerosol Spray | Benzocaine | Risk of methemoglobinemia if maximum dose exceeded |
| Atomizer | 4% Lidocaine | Usually takes longer to work than direct topicalization |
| Nebulizer | 4% Lidocaine | Usually takes longer to work than direct topicalization |
| Syringe | 2–4% Lidocaine | Can be injected through nasal |

trumpet or slowly deposited onto the posterior tongue and run inferiorly to reach the hypopharynx.

Relative contraindications to this block are significant trauma to the nasal cavity and coagulopathy.

## Oral Cavity/Oropharynx

The oral cavity and oropharynx may be anesthetized effectively using several methods for awake intubation. This can be achieved by any number of procedures: gargling several milliliters of 2% to 4% lidocaine and then expectorate the solution; aerosol sprays, such as benzocaine spray; atomization; nebulization; or lidocaine-soaked pledgets that can be directly applied to the mouth and oropharynx. If oral awake intubation is planned, prevention of the patient biting the ETT or scope is needed. The muscles of mastication usually are not blocked, but rather, a bite block or oral airway is inserted.

A direct **glossopharyngeal nerve block** can be performed by either an intraoral or peristyloid approach. For intraoral approach, adequate mouth opening and topicalization for the patient to tolerate the block are needed. The tongue is distracted in an anteroinferior direction, which can be done with a laryngoscope blade or tongue depressor. The base of the tonsillar pillar is identified and a 25 g spinal needle is advanced submucosally at the caudal most portion of the pillar. Aspiration before injection to rule out intravascular location is important given the close proximity of the internal carotid artery. A local anesthetic (5 cc) can then be injected. The same process is then repeated on the contralateral side.

The peristyloid approach requires access to the lateral neck and the ability to identify boney landmarks. The midpoint of a line between the mastoid process and the angle of the mandible is identified. Deeper to this should be the styloid process, which can sometimes be felt with deep palpation. The overlying skin is injected with a wheel of local anesthetic and a 22 g needle is inserted perpendicular to the skin. This is advanced until the styloid process is contacted, usually in 1 to 2 cm. The tip of the needle is then walked off the process posteriorly. Once contact is lost, and after negative aspiration of blood, 5 to 7 cc of local anesthetic is injected. The process is repeated on the contralateral side.

Relative contraindications for glossopharyngeal nerve block include overlying infection and coagulopathy.

## Hypopharynx

The hypopharynx is usually anesthetized by the methods used for oropharynx as the local anesthetic migrates inferiorly. In addition, a syringe with an angiocatheter attached can be used to trickle the anesthetic down the posterior tongue and onto the hypopharynx. If an oral airway is in place, it can be used as a conduit to direct local anesthetic to the hypopharynx. A local anesthetic can also be injected under direct visualization through the port of a fiber-optic scope.

## Larynx

The supraglottic portion of the larynx may be reached by a local anesthetic from methods used for oro- and hypopharynx, such as atomizer, nebulizer, and by trickling the anesthetic down the posterior tongue. A local anesthetic can be deposited on the larynx through the fiber-optic scope as well.

The **superior laryngeal nerve block** can be used to directly block the nerve. The patient is placed in a supine position with the neck fully extended. The hyoid bone is identified by careful palpation. Once identified, it is displaced toward the ipsilateral side of injection and a 25 g needle is advanced until it makes contact with the greater cornu of the hyoid bone. The needle is then walked off inferiorly and advanced 2 to 3 mm to place the tip between the thyrohyoid membrane laterally and laryngeal mucosa medially. After negative aspiration of air and blood, 2 to 3 mL of local anesthetic is injected. This process is repeated on the contralateral side. Alternatively, the superior laryngeal nerve can be topically blocked by applying 4% lidocaine on a pledget to bilateral piriform fossa for several minutes.

Relative contraindications include coagulopathy and inability to extend the neck.

## Vocal Cords and Trachea

The vocal cords and trachea may be anesthetized by several of the above procedures previously mentioned as the anesthetic is aspirated or inhaled. However, they are more reliable and completely blocked by direct injection of local anesthetic through a fiber-optic scope or translaryngeal block.

The **translaryngeal nerve block** is used to anesthetize the true vocal cords and the trachea. It can also block some supraglottic structures as the local anesthetic is coughed out through the vocal cords. The patient is placed in a supine position and the neck extended. The cricothyroid membrane is identified in its midline location. The overlying skin is injected with a local anesthetic. A 22 g needle on a 10 cc syringe with 3 cc of 4% lidocaine is introduced perpendicular to the skin and advanced while continuously aspirating for air. Positive air aspiration indicates that the needle tip is in the trachea. Care must be taken not to advance into the posterior membranous wall of the trachea.

Once the correct position is confirmed, the local anesthetic is injected rapidly as the patient inhales and the needle quickly removed as injection will elicit a cough. Some operators prefer to use a catheter over needle technique with only the catheter left in place while injecting or a larger bore needle to allow for faster injection.

Performing a series of topical and/or regional nerve blocks to anesthetize the involved branches of the V1, V2, V3, glossopharyngeal, and vagus nerves described above will make the experience of awake fiber-optic intubation more tolerable for the patient and significantly increase the chance of a successful procedure.

## TAKE HOME POINTS

- Empathy for the patient undergoing anesthesia for awake intubation and then the intubation itself are of the utmost importance. This is not the easiest patient procedure to have. Keep the chatter in the room down as well. The patient is going to be doing his utmost in concentrating on your instructions to help you get the endotracheal tube through his vocal cords. If the patient needs to catch her breath or a moment, allow that.
- Experienced anesthesiologists will tell you that one of the most important aspects of topicalizing an airway for awake intubation is **taking enough time.** Some parts of the anesthesia should be done as quickly as possible. For example, for translaryngeal lidocaine, inject quickly once the needle is in the trachea and you see the bubbles – no one wants to hang out for a second longer than necessary with a needle stuck into their airway. But do not rush the other steps. Make sure the local anesthetic gel has had enough time to work before successively dilating the naris, and so forth.
- Do not try to substitute heavy sedation for local anesthesia. Be very careful while using droperidol and/or ketamine. We know of multiple instances when the patient appeared ssedated and compliant but later described the experience as extremely traumatic, but they were unable to move or say anything.
- We generally recommend letting the surgical team (especially the OLHN team) know that an awake intubation is indicated or planned, especially if a transtracheal block is planned. They sometimes prefer that the airway not be broached ahead of their procedure.
- Watch as many of these as possible since experience counts. Most anesthesia providers use a lidocaine nebulizer as well as blocks.

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19

# Awake Intubations–Being Able to Do Them Comfortably and Safely for the Patient Is the Benchmark for the Airway Expert

Chauncey T. Jones, MD

"Awake Intubation" is a phrase that often incites immediate concern and fear in patients. Indeed, intubations are frequently performed without sedation during Rapid Response, Code, or trauma situations on conscious or semiconscious patients for life-saving measures. Fortunately, many of these patients do not remember the event because of the severity of their critical condition. However, awake intubations performed under elective or semielective, controlled situations should not be a traumatic experience for the patient.

The anesthesiologists present at an awake intubation, or any airway management, must possess sound Difficult Airway Management skills and should have good bedside manner. Many ASA Closed Claims studies are related to inadequate oxygenation or ventilation. The ASA Difficult Airway Algorithm (and Airway Management Modified for Trauma) is designed to minimize the incidence of situations in which the ability to ventilate and intubate is lost—thus the term "lost airway." Part of the preoperative evaluation by the anesthesiologist is to determine how endotracheal intubation can be safely executed. In most instances, induction of anesthesia followed by asleep intubation is reasonable. However, in certain patients, awake intubation or awake invasive airway access may be safest. For these cases, the focus should be on achieving a safe and effective attempt at awake intubation that is not traumatic for the patient. Note that patient safety is more important than the success of intubation. There are situations when electing to abort the intubation attempt or to achieve a surgical airway are safer endeavors than repeated attempts at a noninvasive airway.

Good physical, mental, and emotional preparation of the patient and establishment of trust by the anesthesiologist will help make the experience of an awake airway better. Physical preparation can be achieved with the help of adequate preoperative workup as indicated, such as sleep study, weight loss, or chemotherapy/radiation to debulk a head or neck tumor. The day-of-procedure preparation involves airway anesthetization (see

Chapter 18). Mental and emotional preparation includes involving the patient and family in knowing what they should expect and what is expected of them. The provider may describe the light or moderately sedated state as opposed to being fully "awake." Asking the patient to take slow, deep breaths during the intubation while imagining their favorite dream or vacation will help reduce emotional stress. This can be later reinforced during the procedure after sedation has been started.

## Indications for Awake Intubation

The decision for an awake intubation may be based on a history of difficult ventilation and/or intubation during prior anesthetics. The indication for surgery may require awake intubation. For example, you may be asked to anesthetize a patient with severe C-Spine instability, requiring awake intubation and awake positioning. Or there may be a patient with a head and neck mass that is partially obstructing the airway or compressing the trachea. Information obtained from history, physical examination, and radiological examinations, or other studies may reveal other potential indications for awake intubation including congenital syndromes that affect the airway abnormal facial structure such as micrognathia, morbid obesity, obstructive sleep apnea with poor respiratory reserve, severe aspiration risk, or significant hemodynamic instability (Table 19.1).

## Nasal Versus Oral

Most intubations are performed orally, unless there is a contraindication. Awake oral intubations may be conducted with flexible fiber-optic (or flexible videoscopic), direct laryngoscopic, or rigid scope/videoscopic techniques.

Nasal intubations are performed for oral surgeries in which the endotracheal tube would hinder the operation, or if the mandible is to be wired closed. Nasal intubation can be performed for patients with poor mouth opening, oral obstructions as with severe angioedema, and to aid patient comfort and oral hygiene if immediate postoperative extubation is not planned. Fiber-optic nasal intubation is often technically easier than oral fiber-optic intubations; a blind nasal intubation can also be employed.

Contraindications to nasal intubation include coagulopathy, abnormal nasal anatomy, sinusitis, and facial trauma where there may be a basilar skull fracture. Complications of nasal intubation include epistaxis, trauma to nasal structures, sinusitis with possible bacteremia, and cribriform plate perforation resulting in cerebral injury/death.

**Table 19.1 ■ Indications for Awake Intubation**

| Category | Example |
|---|---|
| Known by history | History of difficult airway |
| Suspected by examination | 1. Congenital/facial anomalies (micrognathia)<br>2. Morbid obesity, severe OSA, poor respiratory reserve<br>3. Severe airway obstruction: angioedema, extrathoracic mass (head/neck/oral tumor), intrathoracic mass (large mediastinal mass, tracheal/endobronchial lesion) |
| Surgical indication | Unstable C-spine requiring awake prone positioning |
| Medical/trauma | Severe cardiopulmonary instability, facial trauma, severe aspiration risk |

## Techniques

There are multiple ways to perform an awake intubation. The most commonly employed technique is oral or nasal fiber-optic. Keep in mind that fiber-optic scopes were not always available and are not a requirement for awake intubation. Other options include blind nasal, laryngoscopy, any of many rigid scopes, or some combination of techniques. More recently, rigid video laryngoscopes have gained popularity, and can be employed during awake intubations. Keep in mind that, ultimately, the best option may be a surgical airway.

The anesthesiologist should develop a primary plan and at least two backup plans of action and have all necessary equipment for these plans immediately available and checked. Intravenous access, suction, medications, and surgical airway equipment should be available.

After the patient has been mentally and emotionally prepared, anesthetization of the airway should be achieved (see Chapter 18). Light to moderate sedation should be achieved while maintaining spontaneous ventilation. This can be achieved with a combination of midazolam (2 to 4 mg) and ketamine (20 to 60 mg) along with glycopyrrolate (0.2 to 0.4 mg) as an antisialagogue to block the secretory reflex induced by ketamine. Ketamine provides dissociative amnesia and maintains spontaneous ventilation. Midazolam is an amnestic and will block the potential of unpleasant visual hallucinations or vivid dreams from the ketamine. Other options for sedation include dexmedetomidine along with midazolam and/or fentanyl; or judicious use of propofol along with midazolam and/or fentanyl. In addition, have adequate doses of inhaled and/or IV induction medications and paralytics (if desired) immediately available for

induction after successful intubation is positively confirmed.

## Fiber-optic Intubation

First, become familiar with and test the equipment. Verify adequate light source, focus, white-balance, and obtain suction for the scope. Suction through a flexible scope may be inadequate, especially in smaller scopes or with thick secretions. Alternatively, oxygen tubing may be attached to the suction port of the scope to allow blowby of oxygen. This will help keep secretions off the scope camera and provide supplemental oxygenation during intubation.

Scope manipulation is most efficient when the shaft is devoid of slack and held taught. All scope maneuvers are controlled by the dominant hand with the up/down lever, by rotating the wrist, and scope advancement or withdrawal. Test the cuff on the endotracheal tube, usually 7.0 or smaller, and consider softening it in warm solution. Lightly lubricate the shaft of the scope to facilitate easy passage of the ETT. To prevent fogging, antifog solution can be applied to the scope tip, or the tip can simply be placed in warm saline. Patient position can be sitting, semirecumbent, or supine with the head in neutral position. Have several doses of 2 to 3 cc of 2% or 4% lidocaine in a slip tip syringe that can be administered through the scope port as necessary.

For nasal intubation, insert the endotracheal tube into the previously anesthetized, dilated, and vasoconstricted nasal passage, until the tip is in the oropharynx. This serves as a conduit to introduce the fiber-optic scope and guide it toward its destination. Alternatively, some anesthesiologists prefer to have the scope tip threaded through the ETT, but introduce the scope tip first and let it serve as a guide for the ETT.

Once the scope tip is in the oropharynx, the key is to stay midline, maneuver the scope anteriorly, and identify relevant structures. Anterior displacement of the tongue is helpful. This can be done by having an assistant grasp the tongue with gauze or asking the patient to stick out tongue, but remember to be gentle, as it can be a really unpleasant experience to be grabbed by the tongue. Ideally, with advancement of the scope, one should see posterior tongue, epiglottis, arytenoids, vocal cords, trachea, and carina. Knowledge of airway anatomy will allow the operator to stay oriented to midline by spatial relationships of defining structures. Ask the patient to take a deep breath just before traversing the vocal cords. Inject lidocaine onto the vocal cords through the scope if the patient reacts. This can also be done on the carina once in the trachea. The ETT should be advanced into the trachea over the scope while maintaining visualization of the carina by rotating it 180 degrees, so that the flange is oriented anteriorly, to minimize contact and resistance from the arytenoids. Distal ETT location can be confirmed with the scope. With the scope tip at the carina, use the nondominant hand to hold the scope at the proximal end of the ETT as a marker. Without moving the

nondominant hand, withdraw the scope until the distal end of the ETT can just be seen through the scope and stop. The distance from the nondominant hand to the proximal end of the ETT is the height of the ETT tip above the carina.

Oral fiber-optic intubations are similar to nasal FOB except that an oral airway or bite-block should be used to prevent operator injury or scope damage. Several bite blocks designed for fiber-optic intubation exist. Oral fiber-optic intubation is often more technically difficult because a more acute angle must be managed to travel from the mouth to the vocal cords. A jaw thrust from an assistant or asking the patient to displace their jaw anteriorly may help.

## Blind Nasal or Oral Lightwand

These are older, but still very sound techniques that can be used when blood or secretions impede visualization with fiber-optic scope. For blind nasal, prepare the airway as described in Chapter 18. During the procedure, have the patient pant, but not to the point of hyperventilation. Using a 7.0 ETT, introduce it through the nasal passage and slowly advance. Patient respirations can be heard through the ETT. Advance toward the respirations as a guide. If respiratory sounds through the ETT disappear, advancement into the esophagus is likely and the ETT should be withdrawn and redirected. The ETT can be rotated to maintain a midline position. If there is no concern for c-spine instability, the neck can be extended or flexed to help facilitate intubation. Special endotracheal tubes exist that have a drawstring to help manipulate the tip of the endotracheal tube.

If blind nasal is unsuccessful and there is no contraindication to oral instrumentation, the technique can be converted from blind by using direct or rigid video laryngoscopy and Magill forceps to help aid successful nasal intubation.

Oral lightwand stylet intubation can be achieved by advancing a lightwand loaded with an endotracheal tube into the oropharynx toward the larynx while being sure to stay midline. Once the lighted tip of the wand passes through the vocal cords and enters the trachea, obvious superficial illumination of the airway will be noted. The ETT can then be passed off the wand into the trachea. Dimming lights in the room can aid visualization with this technique.

## Awake Laryngoscopy

Awake direct laryngoscopy or rigid video laryngoscopy can be used to quickly assess the difficulty of intubation of a patient once the airway has been anesthetized. Intubation can be performed via this route if feasible. This is a nice approach to take with a patient with moderate suspicion of difficult airway by examination, but with no documented history of difficult airway. If the patient proves not to be a difficult airway, then they are

not unnecessarily given a label of Difficult Airway for all future intubation attempts.

## TAKE HOME POINTS

- You have to bring your best game and most confident and gentle hands when doing an awake intubation. Never skimp on the time you allow to talk to the patient before the intubation. Provide realistic expectations to the patient but be confident and quietly low-key in your approach. Explain carefully the steps you will take to minimize discomfort and what the patient will be asked to do in terms of imagining a snorkel or SCUBA device in his mouth or taking a deep breath.
- Keep the room calm and controlled! If the case is elective do not let anybody rush you, your assistants, or the patient.
- Do not underestimate the effects of the ketamine—the patient may appear to be comfortable and compliant with instructions but you are on the "outside" of the ketamine. What the patient is experiencing in the way of internal sensations may be altogether different.
- There are many ways to perform an awake intubation. Do not get wedded to one technique.
- Be ready for all steps at all times in the intubation. It is not unusual, if the airway has been thoroughly anesthetized, to have the ETT go right through or be very near the vocal cords on the initial placement, even before the scope has been placed. In that case, be ready to hook up to the circuit and assess for $CO_2$ via capnograph before quickly securing the tube and inducing.
- During the intubation, never be harsh with or speak sharply to the patient. If the patient is crying or is at the point of pain and exhaustion, you have to stop.
- Borrow a maneuver from the dentists—agree on a hand motion the patient can make if they are feeling just too overwhelmed or as if they are going to suffocate.
- Do not let the shaft of the scope droop into a swag. Rotate your wrists but not your whole body—you should not be turning yourself sideways. The anesthesiologist's posture should remain essentially neutral except for her hands.
- Rotate the ETT up to 180 degrees to prevent it "catching" on the arytenoids.
- Do not forget that all the "usual" steps of confirming placement in the airway and securing the ETT must take place. Be careful not to accidentally pull the ETT back above the vocal cords or out of the airway.
- Remember that the airway may still be anesthetized at the end of the case, so use caution in assessing readiness for extubation and ability to handle secretions and vomiting.
- See your patient as soon as you can in the PACU to provide information, reassurance, and support. Think always how you yourself would feel about having an awake intubation.

- The ASA Difficult Airway Guidelines are at: asahq.org or http://anesthesiology.pubs.asahq.org/article.aspx?articleid=1918684

## Suggested Readings


American Society of Anesthesiologists Task Force on Management of the Difficult Airway. Practice guidelines for the management of the difficult airway. Anesthesiology. 1993;78:579.

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# Airway Management in the ICU, Including the Dreaded Leaking Cuff—How to Bring Your Best Game

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## Introduction

Anesthesiologists are experts in airway management, including emergency airway management and the management of difficult airways. As such, anesthesiologists are frequently consulted for assistance with airway-related challenges in the intensive care unit (ICU). In this section, we will discuss some common airway issues that arise in the critical care setting, and explore solutions for safe airway management.

## General Principles

Airway management, particularly in critically ill patients, is frequently urgent and can provoke an environment of stress and anxiety among providers. This is counterproductive, leading to disorganization, poor communication, and rushing, all of which set the stage for medical errors, the consequences of which can be disastrous. As an airway expert called upon for consultation, it is imperative that the anesthesiologist maintain a calm demeanor and utilize crisis resource management principles such as clear delegation of tasks and closed-loop communication. It is also necessary to assure that all necessary personnel, equipment, and medications have been brought to the bedside before beginning any airway management procedures, as these are often not immediately available in an ICU setting. Similar to any other procedure, we strongly recommend the use of a team pause to assign specific roles and go over the anticipated steps of airway management, acknowledging that experience with the expected procedure varies among team members.

In addition, critically ill patients often have medical issues that may both necessitate and complicate advanced airway management. These include, but are not limited to, gastrointestinal bleeding; elevated intracranial pressure; heart failure; septic shock; and

trauma to the head, neck, or chest. In order to safely manage the airway in the critical care setting, the approach must be tailored to the individual patient. Structural airway changes may prompt the use of video or fiber-optic laryngoscopy for improved airway visualization. Patients with neurologic insults or hemodynamic instability are often more sensitive to medications for the induction of anesthesia, and appropriate dosing should be carefully considered. Vasopressors and medications for maintaining sedation should be drawn up at the bedside for immediate use if needed. The use of neuromuscular blockade has been shown to be associated with decreased incidence of procedural complications in emergency intubations; however, the choice of agent should be carefully considered in relation to the patient's condition. Succinylcholine, while useful for its rapid onset, and short duration, may be contraindicated in critically ill patients with crush injuries, severe burns, hyperkalemia, prolonged immobility, or complete or partial paralysis. In general, intubation of a patient in the ICU should always be considered a potential difficult airway situation, and difficult airway management supplies should immediately be available at the bedside even if management is anticipated to be routine.

## Issue: "The Endotracheal Tube Cuff Is Leaking, and I Can't Ventilate My Patient!"

The endotracheal tube (ETT) cuff is essential for safe and effective positive pressure ventilation and airway protection in adult patients requiring mechanical ventilation. However, the cuff is susceptible to malfunctions over time. It is made of a thin material (most frequently polyurethane), and can become torn on the patient's teeth when it is initially placed. Its sustained inflation is dependent upon the competency of the pilot balloon, which allows inflation of the cuff via an air-filled syringe, and the tubing that connects the pilot balloon to the cuff.

Some patients may be able to tolerate a reduction in the effectiveness of positive pressure ventilation and loss of PEEP in the setting of a leaking ETT cuff, but many intubated ICU patients lack sufficient pulmonary reserve and may decompensate quickly in this situation. Initially, upon arrival at the bedside, it is important to increase the $FiO_2$ to 100% in an attempt to improve oxygenation and stabilize the patient to allow time for assessment and troubleshooting. Next, check the pilot balloon for inflation. If the balloon is tense, it may be that the cuff is overinflated and has herniated above the vocal cords. In this case, withdraw a small amount of air from the pilot balloon, and assess the ventilator for evidence of improvement of the leak (ability to deliver set tidal volume or inspiratory pressure). If the balloon is deflated, inject a small amount of air into the pilot balloon. If this does not improve the leak or only helps transiently, the leak may be due to an incompetent pilot balloon. It is reasonable to next attempt to temporize

the incompetent balloon by cutting it off, inserting an 18G or 20G angiocatheter into the tubing, and attaching a stopcock to the end of the needle (Figure 20.1). This then allows air to be injected into the ETT cuff and "trapped" in place by the stopcock when it is turned "off" to the pilot tubing. This is also a good solution if you arrive to find the pilot balloon missing or grossly damaged (chewed off, accidentally torn by the patient or a provider, etc.).

If you are unable to resolve the leak through changing the volume of air in the pilot balloon, it is likely that the cuff itself is incompetent. In this situation, or if you are only able to temporize the leak, the next step is to replace the ETT.

## Issue: "I Need to Change the ETT or Extubate This Patient, but I'm Concerned About a Difficult Reintubation."

There are several strategies to increase your chances of successfully replacing an ETT or preventing a failed extubation and subsequent difficult reintubation. Prior to attempting extubation or ETT exchange, it is necessary to ensure that the patient's clinical status has been optimized. Specifically, if the plan is for extubation, the patient's pulmonary and neuromuscular readiness for extubation should be confirmed via a spontaneous breathing trial in accordance with the current standard of care. This allows the calculation of a rapid shallow breathing index (RSBI), also known as a Tobin Index, which has been validated as a predictive index of successful extubation. This calculation is a simple ratio of respiratory rate to tidal volume in liters; an RSBI of less than 105 is predictive of readiness for weaning from the ventilator. Another common pre-extubation assessment is a cuff leak, which can be calculated as the percentage difference of exhaled tidal volume with ETT cuff up and down in volume control mode, divided by the exhaled tidal volume with the ETT cuff up. In one study, a cuff leak of greater than 15.5% had a negative predictive value of 96% for the need for re-intubation; however, the positive predictive value of a cuff leak less than 15.5% was only 25%. Thus, the lack of a significant cuff leak should not necessarily preclude extubation, but may be used to increase clinical suspicion for postextubation stridor or the potential need for reintubation. Administration of steroids may be considered, and extubation or tube exchange temporarily postponed for several hours if the patient is otherwise clinically stable. Finally, thorough suctioning of the existing endotracheal tube and oropharynx should be performed before proceeding with extubation or tube exchange.

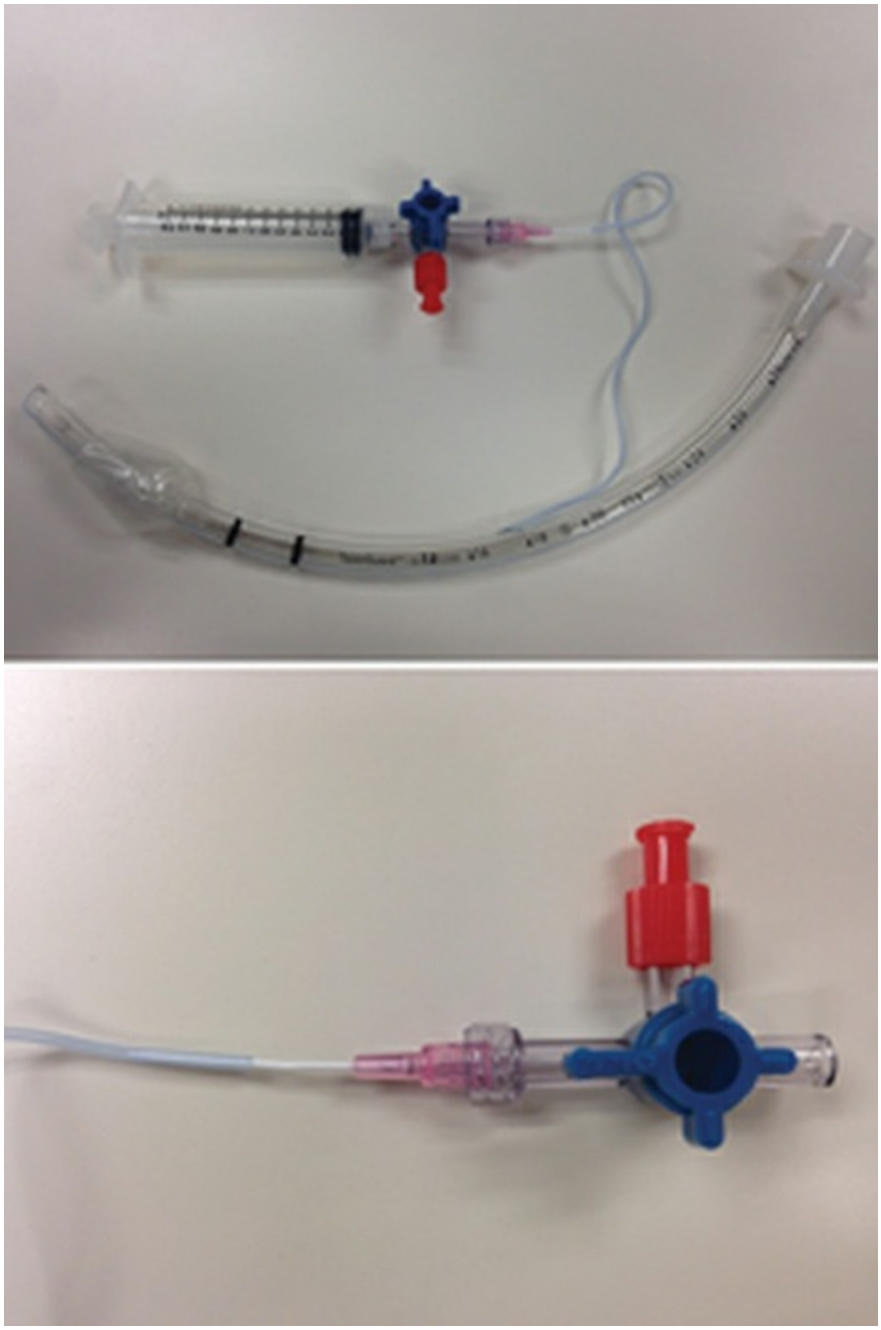

**Figure 20.1.** ETT with missing pilot balloon. A 20 g angiocath has been inserted into the end of the pilot balloon tubing and attached to a three-way stopcock with syringe, which has then been used to inflate the cuff (top). Closing the stopcock to the pilot balloon tubing prevents air from leaking out of the cuff (bottom).

Once the patient's status has been optimized, or if the patient's clinical status necessitates more urgent intervention (e.g., tube exchange for a persistent leak, inability to oxygenate or ventilate, high risk of significant aspiration), a plan should be formulated for immediate exchange. If the patient has a known straightforward airway, it may be reasonable to simply extubate and reintubate the patient. The caveat to this approach is that many factors may increase the difficulty of intubation in a patient

hospitalized with critical illness, including hypervolemia, decreased pulmonary reserve, challenging patient positioning, and laryngeal edema related to the presence of the ETT itself.

In a patient with a known difficult airway, or with a predicted possibility of difficult re-intubation, it is prudent to consider alternative approaches. One such approach is the use of an exchange catheter. These catheters are long, flexible plastic devices that pass through the lumen of the endotracheal tube and may be solid or may have a hollow lumen of their own to allow oxygen delivery (and jet ventilation if necessary) while in place. Exchange catheters allow endotracheal tube exchange to occur via a Seldinger-type technique; that is, they pass between the vocal cords, acting as a "stent" and maintaining a pathway into the trachea over which the new endotracheal tube can pass. In a patient in whom extubation is planned, rather than ETT exchange, the exchange catheter can be left in place for a period of time after extubation in order to assess the patient's respiratory function; if the patient fails extubation, the exchange catheter will already be in place to facilitate reintubation. While these devices can be helpful in preventing complete airway loss, none of them guarantee a successful intubation as they can slip out of the trachea into the esophagus. Therefore, you may still consider performing direct or indirect (video or fiber-optic) laryngoscopy during re-intubation with the exchange catheter to allow visualization of the glottis and displacement of the tongue and soft tissues.

A fiber-optic bronchoscope can also be useful in a high-risk extubation or tube exchange. Although the patency of the airway cannot be fully assessed in this situation, fiber-optic bronchoscopic examination with an ETT in situ can provide useful information regarding the presence of supraglottic edema or tissue injury. In addition, if tube exchange is necessary, the bronchoscope can be preloaded with an endotracheal tube, advanced adjacent to the ETT in situ, and then used to intubate the cords immediately following withdrawal of that tube. It may be most appropriate to choose a specialized endotracheal tube designed with a flexible tip to facilitate easier passage between the vocal cords.

A laryngeal mask airway (LMA) can also be inserted as a temporary means for oxygenation and ventilation. While the LMA does not pass through the vocal cords and is not a long-term airway solution, it can alleviate airway obstruction due to the tongue or upper airway tissues. Importantly, an intubating LMA can facilitate passage of a fiber-optic bronchoscope into the larynx, over which an endotracheal tube can be advanced through the vocal cords and into the trachea.

While these techniques, particularly the use of an exchange catheter, have been shown to be successful in most cases (92% in one study), the anesthesiologist must always be prepared for them to fail. In the case of postextubation stridor, administration

of nebulized racemic epinephrine may reduce edema. Heliox, a mixture of helium and oxygen (up to 79% helium), replaces nitrogen in air with less-dense helium. This decreases the turbulence of gas flow through the high-resistance glottis, allowing for increased oxygen delivery to the lungs. Finally, the anesthesiologist must always be prepared to follow the American Society of Anesthesiologists' difficult airway algorithm. If the above techniques fail to safely secure the patient's airway, an emergency surgical airway may be required.

## Issue: "My Patient's Tracheostomy Device Is Dislodged."

In a patient with a "fresh trach," which refers to a new tracheostomy in which the stoma has not yet healed (generally <1 week old), the stoma will close and collapse very quickly if the tracheostomy device is no longer in place. Thus, attempts at readvancing a dislodged tracheostomy device are unlikely to be successful if the tracheal lumen is not visible or palpable. Repeated attempts at blind readvancement may result in creation of a false passage and airway loss; ventilation of a false passage can cause extensive subcutaneous emphysema, bilateral pneumothoraces, and cardiovascular collapse.

Any dislodgement of a fresh tracheostomy should be considered an airway emergency. If a patient is spontaneously breathing and able to adequately ventilate and oxygenate around the tracheostomy site, there is usually time to contact the surgical service that placed the tracheostomy and ask for assistance with replacing the device. However, emergency difficult airway management equipment and ICU provider presence at the bedside are imperative given the possibility of a rapid clinical decline.

If the tracheostomy device is not completely dislodged, it is reasonable to attempt once to readvance the device with the obturator in place (to soften the tip of the device); if this procedure goes smoothly, placement must still be confirmed via capnography. If the trachea is not easily visualized, the forceps contained in a surgical tracheostomy kit can be used to explore the tracheostomy site, locate the tracheal lumen, and allow safe replacement of the tracheostomy device. A fiber-optic bronchoscope can also be a useful tool for visualizing the tracheal lumen and in confirming correct placement of the tracheostomy device following readvancement. Any resistance to ventilation or passage of a suction catheter through the tracheostomy following readvancement is a sign of the creation of a false passage (tracheostomy device in pretracheal soft tissues) and should preclude further attempts at ventilation through the tracheostomy unless it can be readvanced or replaced by a qualified surgical or critical care provider.

Mechanically ventilated or other critically ill patients often have very little pulmonary reserve; tracheostomy dislodgement and the resulting lack of ventilation and oxygenation in these patients is likely to be followed by rapid desaturation and/or hemodynamic instability. In this situation, bag-mask ventilation should be performed,

and a protected airway should be established from above via orotracheal and nasotracheal intubation in order to stabilize the patient.

One exception to these general rules is the patient who has had a total laryngectomy. These patients no longer have a connection between their oropharynx and trachea, as the proximal end of the trachea now forms the tracheostomy. Total laryngectomy patients can therefore no longer be intubated from above; however, the replacement of a dislodged tracheostomy device should not carry the risk of false passage creation since the trachea is clearly visible and sutured to the skin. Thus, a dislodged tracheostomy device can be safely and quickly readvanced in these patients.

## Summary

Anesthesiologists are often called to help with difficult airway management situations in the ICU. It is important to be prepared for complex management of a high-risk patient. Although these situations can be emergent, often there is adequate time to create, communicate, and implement a plan tailored to the patient's specific needs and to utilize one or more of the many tools available for high-risk airway management. As an airway expert, the anesthesiologist must be able to provide calm leadership in an unfamiliar environment in order to maximize patient safety.

### TAKE HOME POINTS

- It may be possible to temporarily stabilize a leaking endotracheal tube cuff if the leak is caused by a compromised pilot balloon or pilot tubing.
- Endotracheal tube exchange catheters, laryngeal mask airways, and a flexible bronchoscope can be useful adjuncts when extubating patients with suspected difficult reintubation.
- The displacement of a fresh tracheostomy should be considered an airway emergency.
- If the trachea cannot be directly visualized in a patient with a dislodged tracheostomy, an airway should be established from above.

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21

# Ludwig's Angina

Anne Lemak, DMD, Todd M. Oravitz, MD, and William John Wallisch IV, MD

Septic cellulitis of the submandibular, submental, or sublingual spaces bilaterally is also known as **Ludwig's angina**. Ludwig's angina is most often the result of a dental abscess of the second or third mandibular molars, prior to or following tooth extraction, and will present as diffuse swelling of the floor of the mouth and airway. Symptoms can arise quickly and may consist of neck swelling, redness and pain, fever, chills, fatigue, earache, drooling, confusion, and eventually airway collapse. There is sometimes a notable lack of visible abscess on the alveolar ridge. Prompt treatment is compulsory to prevent the spread of infection and asphyxiation associated with subsequent airway edema.

Ludwig's angina is typically caused by hemolytic streptococci from normal oral flora; however, it may be a combination of both aerobic and anaerobic bacteria resulting in the infectious process. The swelling in the floor of the mouth may be so extensive that the tongue is displaced upward and posterior occluding the mouth and oropharynx, and if left untreated, the infection may spread caudally into the thoracic cavity resulting in an abscess of the pericardium and lungs, or throughout the body as septic shock. Patients may present with extreme lethargy, dehydration, and shortness of breath, and **will require immediate medical attention.**

Treatment of the Ludwig's angina patient depends on the extent of airway involvement. A less extensive case may simply require incision and drainage, surgical decompression, and a full course of broad-spectrum antibiotics. However, in order to determine the degree of inflammation, a CT scan of the head and neck may be warranted as the first step to treatment. A thorough history and physical examination should also be obtained and the patient's anesthesia **team should work in conjunction with the surgeons to devise a comprehensive treatment plan.** Managing the Ludwig's patient may be complex, as he/she may be unable to talk or open his/her mouth adequately for incision and drainage of the affected area. Difficulty in opening the mouth, in combination with airway edema and displacement of the tongue, presents the potential for serious anesthetic risk and complication. A **definitive anesthetic strategy**, along with backup preparations is highly recommended for any Ludwig's patient.

The anesthesia provider(s) should carefully examine the airway, by evaluating all the usual components including Mallampati class, oral opening, cervical range of motion, thyromental distance, and presence/absence of teeth. In addition, in the Ludwig's angina patient, the degree of airway edema (both clinically and radiographically), ability to swallow, amount of secretions, and mobility of the tongue need to be assessed. Tongue mobility is a fairly unique consideration in the Ludwig's patient, as the disease process itself involves the submandibular space, which may become edematous and hardened. This is important with respect to airway management because during routine laryngoscopy the tongue is displaced into the submandibular space. In the Ludwig's patient, if that space is diminished or unavailable, it can make visualization of the vocal cords and subsequent intubation quite difficult. The anesthesiologist and surgeon may only proceed after this checklist has been carefully evaluated and a clear plan has been devised.

The airway of a Ludwig's patient may be deceiving; it may appear to be unobstructed when the patient is awake and spontaneously breathing but that may change dramatically after induction and paralyzation. Topically anesthetizing a patient's larynx and trachea in order to take an "awake look" may not be beneficial as visualization of laryngeal anatomy postinduction may be greatly reduced compared to that than of the awake patient due to decreased laryngeal muscle tone. Muscle relaxants may allow the edematous tissues adjacent to the trachea to relax after induction and occlude an airway that was patent in an awake Ludwig's patient, possibly resulting in difficult, if not impossible, ventilation and/or intubation. Multiple intubation attempts or manipulations of a Ludwig patient's airway can be especially harmful, as it may cause the accumulation of blood and secretions in the pharynx and can potentiate further complications in already dire circumstances. **For these reasons attempts at direct laryngoscopy after topicalization of the airway is not advised in the Ludwig's angina patient**.

For the mildest cases of Ludwig's angina, traditional direct laryngoscopy after routine induction may be sufficient. If this route is undertaken it is advisable to have emergency airway equipment in the operating room should either ventilation or intubation prove more difficult than anticipated. For example, a laryngeal mask airway (LMA) may prove more effective than bag-mask ventilation if soft tissue collapse is a problem. Even more important than emergency airway equipment, however**, is the presence in the operating room during induction of an experienced surgeon ready to provide a surgical airway should ventilation and intubation prove impossible.**

For moderate Ludwig's angina patients**,** a safer means of obtaining a secure airway is to carry out an awake intubation, where the patient retains consciousness and spontaneous respirations until the endotracheal tube is in place. Prior to beginning an

awake intubation, the patient must be fully informed of what he/she is about to experience and he/she must be willing and able to cooperate with the anesthesiologist in attaining adequate airway anesthesia.

To overcome the laryngeal reflexes and anesthetize the airway, a variety of methods may be used. Supraglottic anesthesia can be obtained via a nebulized topical anesthetic followed by lidocaine-soaked pledgets, gargles, or sprays. Bilateral superior laryngeal nerve blocks may also be performed to anesthetize the cricothyroid muscle and to ameliorate sensation from the base of the tongue to the vocal cords. Patients with evidence of a tumor at the site of block and those with an active infection at the site of injection would be contraindications to the use of this nerve block. As this block is designed to reduce sensation in the airway, it should only be used in patients with a full stomach when the benefits of maintaining spontaneous ventilation outweigh the risks of rapid sequence induction/intubation. Because tracheal nerve blocks can be somewhat uncomfortable, dexmedetomidine, benzodiazepines, and/or opioids may be used to offset the stress associated with this procedure. Caution must be taken to ensure that the patient maintains spontaneous respirations and does not become oversedated. Infraglottic anesthesia may also be warranted, and can be achieved via a transtracheal nerve block by injecting via the cricothyroid membrane with 2% lidocaine.

Once full airway anesthesia is accomplished, the anesthesiologist can proceed with intubation. The endotracheal tube can be passed by means of a flexible bronchoscope, a direct vision, lighted stylet (Shikani optical stylet or retromolar scope) or via an intubating laryngeal mask airway (Fastrach LMA or using an Aintree catheter and flexible bronchoscope). Care must be taken to avoid contacting abscessed areas in the mouth and oropharynx with airway instruments to try to prevent purulent discharge from migrating into the lungs. Once the trachea has been successfully intubated, and ETT position confirmed with positive end-tidal $CO_2$ and auscultation, the anesthesiologist can induce general anesthesia and the surgical procedure may begin. **An experienced surgeon should be present in the operating room, ready to do an emergent tracheostomy, during any awake intubation attempt.**

One important point to remember when considering awake intubation in a patient with Ludwig's angina is that airway topicalization itself may be difficult. The infected laryngeal tissues will likely be acidotic, which means that a greater percentage than normal of the local anesthetic will remain in its ionized form. Since the unionized form traverses the neuronal membrane, the effectiveness of the local anesthetic may be reduced and the degree of airway anesthesia may be suboptimal.

Ludwig's angina patients who present with advanced disease, evidenced by labored respirations, drooling, or limited mouth opening, are candidates for elective awake tracheostomy. An experienced surgeon should always be present in the operating room,

ready to perform an emergent tracheostomy, regardless of the apparent level of airway involvement.

The decision to extubate the patient upon conclusion of the surgical procedure is based on the extent of the infection and the level of edema present. For more serious infections, a timely course of antibiotics may be necessary to alleviate the swelling and allow for an unimpeded airway prior to extubation. For patients of this type, who were preoperatively classified as a "difficult" airway, the decision to remain intubated should be made, along with arrangements for postoperative sedation. All patients with considerable edema of the pharynx, submandibular space, and tongue, should remain intubated, until it is certain that a natural airway can be maintained. It is not uncommon for a Ludwig's patient to remain intubated and mechanically ventilated for several days postoperatively, until extubation criteria have been met.

Regardless, if extubation occurs in the operating room following surgery or in a delayed fashion in the ICU, documentation of a leak around the endotracheal tube (with the cuff deflated) occurs at a peak pressure of 20 cm $H_2O$ or less of pressure.

This helps to ensure that the edema has subsided and a patent airway is present without the endotracheal tube in place. In patients who have required a tracheostomy, maintaining the tracheostomy site is inevitable; however, whether the patient is kept on mechanical ventilation or allowed to breathe spontaneously is dependent on the patient's prior medical history (i.e., presence or absence of lung disease, localized versus systemic infection, etc.).

In any Ludwig's angina case, meticulous attention must be paid to devising and executing the safest and most thorough anesthetic and surgical plan. A thorough understanding of the difficult airway algorithm is paramount as well as a close collaboration between all involved parties on the surgical and anesthetic teams. A prompt and comprehensive strategy is the key to enduring the most serious of circumstances challenging a Ludwig's angina patient.

## TAKE HOME POINTS

- Ludwig's angina is most commonly seen after dental work. A typical scenario is for the patient to present in the evening or on a weekend after an urgent call to the dentist or endodontist that resulted in referral to the emergency department. These are true airway emergencies. For some reason, they seem to come in as call cases.
- These airway cases can be complicated with loose and dislodged teeth. Poor dentition or recent dental work is how the patient gets into a Ludwig's angina situation in the first place.
- Do not neglect to evaluate the airway basics. Also assess tongue mobility, drooling

and/or pooling of secretions, and ability to swallow.

- You will not cause a patient with Ludwig's angina to go into airway collapse by just looking at him/her, **but remember that the first manipulation of the airway must come with the ability to definitively secure the airway**. Patients have and will go into airway collapse with the most gentle effort "to spray them up and take a quick look." Do not do this while you are waiting for the surgeon! The editors are aware of at least one mortality that has occurred from a "quick look."
- For this reason, experienced anesthesiologists will not start to secure the airway unless there are personnel and equipment available for a surgical airway. This usually means the actual presence of an experienced surgeon, ready to do a surgical airway.
- There is no defined technique for these airways. The best technique is a conservative technique that the surgeon has collaborated on and agreed to. This can be either a very careful awake or anesthetized airway.
- The editors have taken care of multiple cases of Ludwig's angina. We have seen airways that have been both more and less severe than we anticipated. In one case, direct laryngoscopy proved to be impossible and the case was managed with a laryngeal mask airway (this was years before Glidescopes). In another case, the airway was so severely compromised that the surgeon agreed to be present, scrubbed in, and with his tracheostomy tray opened. In the worst case the editors have seen, both a head and neck and a thoracic surgeon were present in the room at induction as the infection had tracked down to the thoracic inlet.
- These are "rare" airway cases that are not all that rare. Pretty much every senior anesthesiologist will have done at least one case. Put this case on your list of cases to ask more experienced clinicians about when you are sitting around in the anesthesia office at the end of a call shift.

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22

# Jet Ventilation—How to Adequately Handle This Exotic Ventilation Technique and Earn the Admiration of Your Spectators

Peter Biro, MD DESA

When jet ventilation (JV) was invented and introduced to the market in the mid-seventies, many preconditions of safe application—that we consider nowadays absolutely necessary—were not yet available. The modern components of total intravenous anesthesia such as propofol and remifentanil were still far from being introduced, and the occasional use of nitrous oxide and volatile anesthetics with JV was cumbersome and extremely likely to pollute the ambient air. Effective monitoring of gas exchange, as is now routine with pulse oximetry and capnography, was also in the early stage of preclinical development. The first few generations of jet ventilators lacked a means to control airway pressure (Paw), thus bearing the risk of lung injury in case of sudden air trapping. In addition, the conditioning (warming and humidifying) of the jet gas was then unavailable, and the importance of this measure was not yet fully appreciated. Present JV technology, along with effective monitoring devices and the many choices of short-acting anesthetic drugs have all enabled safe application of JV for specific indications. The use of this technology has a high benefit/risk ratio, when used properly, regularly, and by personnel that are familiar with the device and its safe application. However, a general rule is that anywhere a jet ventilator is used, a conventional anesthesia ventilator or at least a manually operated circuit must also be available, both as a transition device between conventional and JV (in both directions), as well as a backup technique to be employed if JV becomes insufficient to provide the necessary gas exchange. Another important issue is that JV needs to be practiced regularly. Just occasional application of JV by inexperienced users such as novices in anesthesia ventilation, the hospital's janitor, or the confectioner from the neighboring cake shop should rather keep their hands off.

## Accepted Indications for JV

- Upper airway diagnostics and surgery
- Vocal cords interventions
- Sleeve resections of the trachea
- Tracheal surgery in the vicinity of the carina
- LASER light ablation of tracheal obstructions
- Radio-frequency, cryo-, or thermal ablation of liver tumors
- Ablation of ectopic heartbeats

The indications for JV use in airway surgery are justified because of the lesser space requirement in the operated airway, thus offering better visibility and access for the surgeon, and in certain cases JV ventilation is still possible if the airway is open to the atmosphere. For the last two indications in this list, the justification is that under JV with a high frequency (>120 cycles per minute), the respiratory moves are limited and the targeted organs move less than under conventional ventilation or spontaneous ventilations. In these cases, JV can be applied via regular tracheal tubes too, but the connection between tube and jet line must be kept open to the atmosphere that way, that passive exhalation is possible.

## Insufficient Oxygenation

Problems with oxygenation are occasionally observed with JV, and these usually appear in one of two forms. A sudden drop in saturation may be the result of an acute pneumothorax. This should be quickly verified and treated by thoracic drainage. A slow decline in saturation is usually due to insufficient ventilation or limited pulmonary diffusion capacity. Underlying these cases, there is usually a combined restrictive–obstructive lung disease, often associated with a significant reduction in vital capacity. A whole series of technical measures can be utilized to counteract the gradual decline in oxygen saturation. First, the oxygen concentration in the jet gas should be increased. If this measure doesn't achieve the desired success, one can increase the driving pressure (DP). Further steps to improve oxygenation may include the extending the inspiration duration (ID), reducing the ambient air entrainment (by adding an $O_2$ "bias flow") or switching from supraglottic to the more efficient infraglottic JV. If these measures have been exhausted and still no adequate oxygenation was achieved, then one must consider either the use of intermittent conventional ventilation or switching entirely to positive pressure ventilation.

## Insufficient Carbon Dioxide Elimination

Hypercapnia can be observed in patients with predominantly obstructive lung disease (COPD). Often these are obese individuals with reduced thoracic compliance. The

technical possibilities to counteract a continual rise in the $PaCO_2$, include an increase in the DP up to the available technical limits. An upper limitation of the DP is given only from the available pressure of the gas sources, which are usually in the range of 55 to 65 PSI. In patients who are ventilated with the maximally available DP, and in whom $PaCO_2$ rises further, one must decide what degree of hypercapnia is acceptable. In general, one can assume that an increase of $PaCO_2$ to the extent of 1.5 times of the baseline can be tolerated at the end of surgery. At this point, the $CO_2$ status can be normalized either by intermittent or definitive switch to conventional ventilation via an endotracheal tube or a laryngeal mask.

## Increasing Airway Pressure

The Paw during JV is mainly determined by the set DP and its interaction with the airway anatomy of the patient. As long as no obstacle to the gas outflow exists, the Paw remains very low, in the magnitude of a few mmHg. Ventilation frequency and the duration of inspiration have little direct impact on the Paw, except in extreme settings when there are remarkable changes in gas volume. In addition, the size and shape of the jet nozzle and the airway geometry are important factors as well. Since high Paw directly bears on the risk of lung distension and lung injury, a continuous measurement of Paw is required, as well as an automatic cessation of ventilation if a user-set pressure limit is exceeded. A state-of-the-art jet ventilator is ideally equipped with redundant Paw-monitoring. Via a dedicated line connected to a multilumen jet catheter, the Paw is continuously measured and displayed as a pressure curve indicating peak inspiratory pressure (PIP), mean airway pressure (mPaw), and end expiratory pressure (EEP). Separately, the pressure course is simultaneously measured in the jet line, but due to technical limitations, this is only possible during the short break between the insufflations. For this reason, another alarm limit is set (pause pressure [PP]), which needs to be undercut at the end of each cycle before the next insufflation can be released. In infraglottic JV, this type of double Paw-monitoring needs to be applied via a jet catheter with two lumens. The measured Paw in the trachea is not identical to the Paws in various portions of the lung, but may be viewed as a reasonable approximation. This value can be used to activate the necessary alarms and to keep the Paw within the pressure limits determined by the user.

## JET Gas Conditioning

Prolonged ventilation with unconditioned (dry and cold) ventilation gas may cause damage to the tracheobronchial mucosa. This can range from a temporary disturbance of mucociliary clearance with risk of subsequent infection, to a life-threatening necrotizing

tracheobronchitis. Besides the duration of ventilation, other predisposing factors to mucosal injury include circulatory instability, physical pressure on the mucosa, and pre-existing mucosal damage, as is the case in smokers. Less dangerous, but also undesirable, is the rapid occurrence of hypothermia during unconditioned JV. After only15 minutes of unconditioned JV, a drop in the body core temperature up to 2°C is possible. Ideally, jet gas is conditioned by heating it to 37°C and enriching with 100% relative humidity before it leaves the nozzle. Heating of the jet gas without humidification is inefficient, since dry gas has a much-reduced capacity to transport heat, and would dry the mucosa even more. Conversely, exposure of the gas to water without heating is not an effective means of humidification, resulting in intratracheal water infusion, which could be harmful. This means that there is no alternative to maximal conditioning as far as it is technically possible. Neither can be stated as a maximal application of unconditioned JV; in all cases conditioning should be applied.

The conditioning level may be gradually regulated from 0% to 100%, which is not to be confused with the percentage of relative humidity. Modern JV equipment automatically adjusts the amount of water and heating energy to the supplied gas volume. The essential message for the user is that one should always work with the maximum possible conditioning to ensure the best tolerance of JV. A disadvantage of high-performance conditioning is, however, that the exhaled water vapor blurs the surgeon's laser microscope. Only this circumstance is an appropriate reason to reduce the gas conditioning, in small increments, to the extent that the visual disability is avoided for a restricted duration of time.

## TAKE HOME POINTS

- JV has a limited list of indications—but in these special circumstances, it is far superior to conventional ventilation methods.
- A JV working place must include one regular ventilation system as a backup and for intermittent application in case of necessity.
- JV is very different from conventional anesthesia ventilation, and therefore it needs sufficient expertise and regular practicing.
- During JV, only total intravenous anesthesia is suitable.
- The safe application of JV requires redundant Paw measurement and gas conditioning (gas heating and humidification).

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23

# High-Frequency Jet Ventilation—The View From Philadelphia

Jeff E. Mandel, MD MS

High-frequency jet ventilation (HFJV) is a modality that has been associated with tracheal surgery and ARDS. While HFJV has lost favor in the ICU, it is still the standard in laryngeal and tracheal procedures. An emerging area for HFJV is in reduction of respiratory motion artifact during interventions such as pulmonary vein isolation, radiofrequency ablation, and external beam therapy. While readers outside the United States may have access to other devices such as the TwinStream (Carl Reiner, Vienna, AT), the only FDA-approved high frequency jet ventilator is the Monsoon (Acutronic Medical Systems, Fabrik Im Schifli, CH), and this discussion will refer to the properties of that device.

## Physical Principles

HFJV employs different physical principles than conventional ventilation to achieve oxygenation and removal of carbon dioxide. Jet ventilation typically employs a unidirectional jet; inspiration is the result of this high velocity narrow cylinder of gas travelling down the core of the airway; exhalation is passive, and for all practical purposes is plug flow. There is some mixing between these two streams, but the majority of the fresh gas arrives at the distal airway free of $CO_2$. This allows for removal of $CO_2$ with tidal volumes less than the anatomic dead space, and is referred to as axial dispersion. These small breaths stack one upon another to increase the volume of the lung above the closing capacity. While some useful information can be derived from monitoring the pressure in the airway, monitoring the volume of the chest and abdomen with modalities such as respiratory inductance plethysmography (RIP) provides more insight.

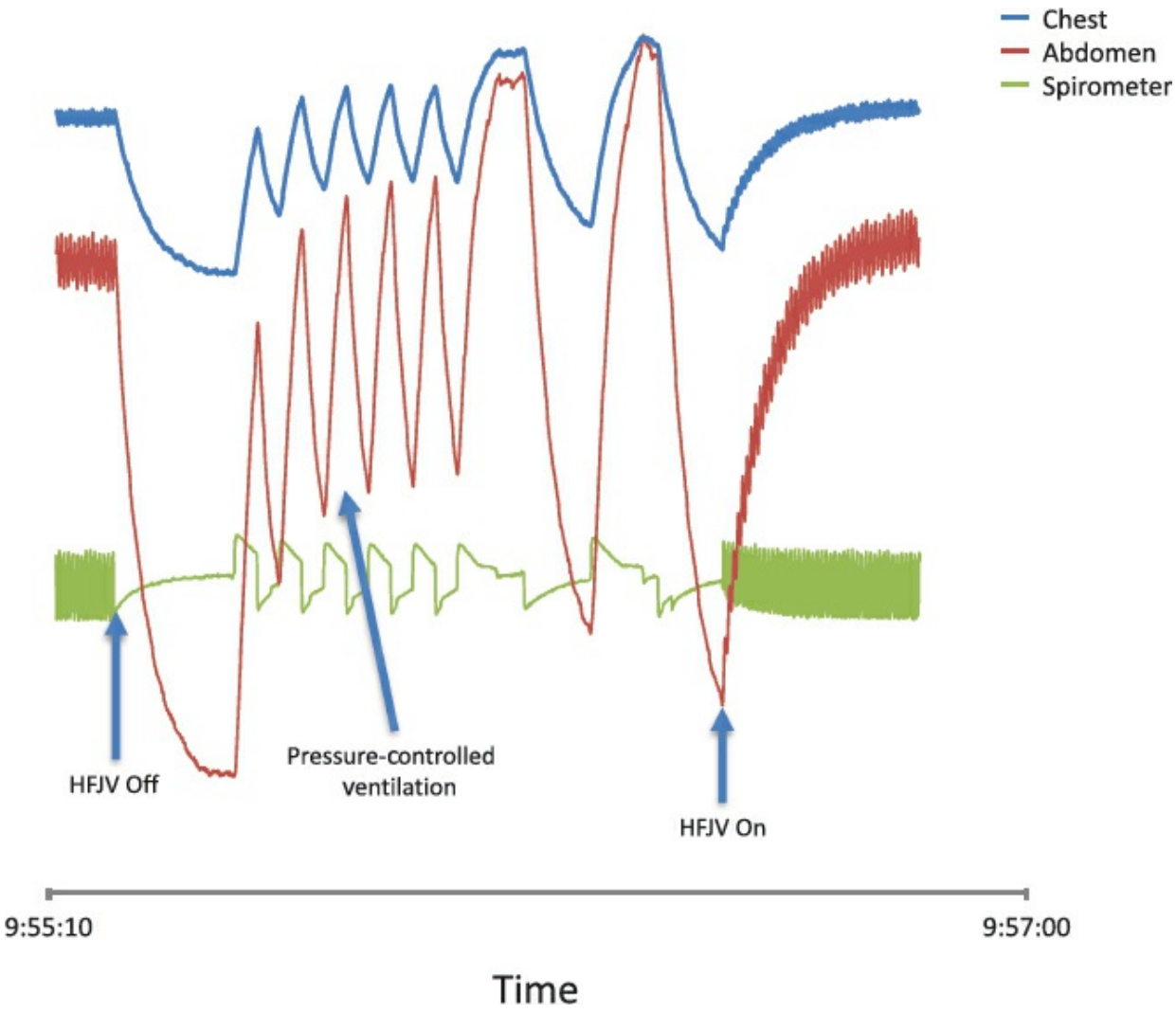


**Figure 23.1.** Transition from HFJV to pressure-cycled ventilation and back. The blue line is the chest volume, the red line is abdominal volume, and the green line is spirometer flow. (Jeff E. Mandel MD MS, unpublished data.)

## Clinical Use and Principles

This is illustrated in Figure 23.1, which shows the RIP chest (blue) and abdomen (red) signals, and the signal from a spirometer in the expiratory path during the transition from HFJV (driving pressure 20 PSI) to pressure-controlled ventilation (pressure 18 cm $H_2O$) for 5 breaths followed by 2 large manual breaths, then return to HFJV.

Two features should be noted. First, upon cessation of ventilation, the volume of the chest and abdomen exhibit an exponential drop over about 30 seconds. The volume is restored with the institution of either mode of ventilation, with the peak inspiratory volumes being similar. While not depicted on the graph, the circuit pressure during HFJV was approximately 5 cm $H_2O$, and the gradient in pressure between the trachea and the anesthesia machine was negligible. Second, the time course of breath stacking with HFJV and conventional ventilation are similar—4 breaths with 12 breaths/min

versus 40 breaths at 120 breaths/min.

When outflow is unobstructed, the pressure in the airway does not reflect the pressure in the alveolus, as the significant pressure gradient is across the small airways. This does not mean that there is no reason to monitor pressure in the airway—it is critical to detection of outflow obstruction. The practical issue is when using the Monsoon whether to monitor pressure with pause pressure (PP) or peak inspiratory pressure (PIP). PP is measured during the pause between breaths (hence the name), and only requires the blue-tipped hose, while PIP requires the addition of red-tipped hose and a second monitoring site. While this site may be adjacent to the point of insufflation (as occurs with the LaserJet catheter), it is never proximal to the point of insufflation. Why does this matter? When using HFJV in the setting of tracheal strictures, there may be a significant pressure gradient across the stricture, but this can be adequately detected by PP.

Another point to be gleaned from Figure 23.1 is that lung volume is modulated by driving pressure, and it is quite possible to increase lung volume enough to reach the elastic limit of the lung. The correct approach to hypercarbia may not be an increase in driving pressure, it may be a decrease. Additionally, as driving pressure is increased, the increase in intrathoracic pressure may lead to impaired cardiac filling and hypotension. Before concluding that the patient cannot be ventilated with HFJV, try decreasing the driving pressure.

## $CO_2$ Monitoring

Noninvasive monitoring of $CO_2$ elimination during HFJV can be accomplished by two approaches. HFJV can be interrupted (as was done in Fig. 23.1) and several tidal breaths delivered, either by the anesthesia machine, or by using the $ETCO_2$ feature of the Monsoon 3. Alternatively, transcutaneous monitoring of $CO_2$ can be performed using monitors such as the Sentec Digital Monitor (Sentec Inc, Fenton, MO), which provide continuous monitoring of $CO_2$ elimination.

## Other Clinical Considerations

When HFJV is employed during laryngotracheal procedures, it is to avoid placement of an endotracheal tube in the field. With newer applications for motion artifact reduction, placement of an endotracheal tube or laryngeal mask is routine, and connection of the tube to the anesthesia circuit affords a convenient way to transition back to conventional ventilation and allows the use of a heat/moisture exchange (HME) filter to conserve inspiratory humidity. This however puts the entire anesthesia machine in the outflow path of the jet. One of the features of the Monsoon is the ability to introduce water into

the inspired gas (hence the name), but when this is done distal to the HME, the filter rapidly becomes saturated with water and obstructs the outflow path. Failure of the circuit expiratory valve, a closed adjustable pressure limit (APL) valve, or a failed scavenger positive pressure relief valve can cause an obstructed outflow path as well. All of these will result in the Monsoon alarming for sustained pressure and shutting down. Since the jet is introduced distal to these points of failure, isolating the problem begins at the jet connection to the patient and works back toward the anesthesia machine.

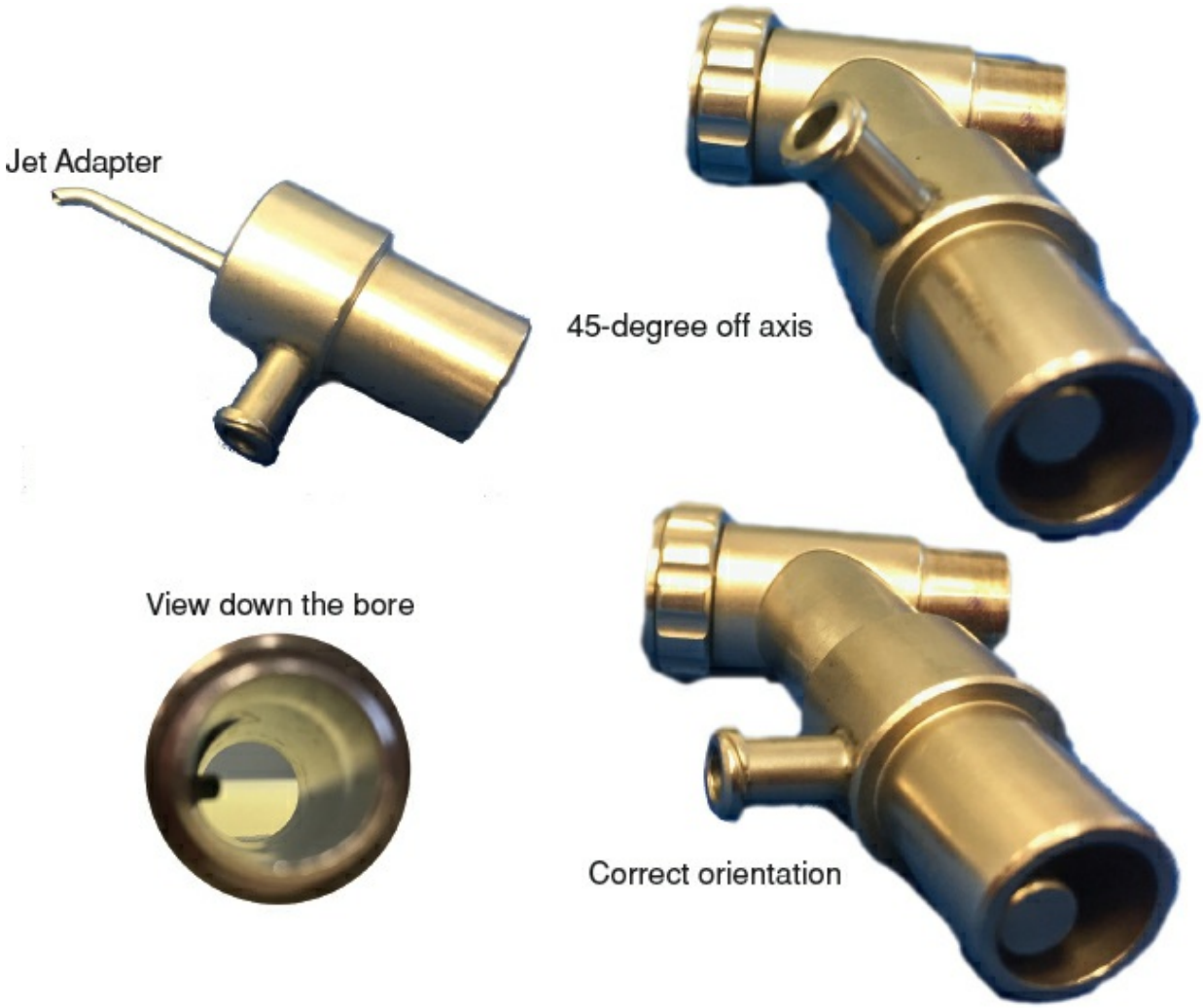


**Figure 23.2.** The connection of the jet ventilation adapter to the ocular body of the Efer-Dumon bronchoscope, illustrating the ability of the jet nozzle to rotate off the long axis of the bronchoscope. Counterclockwise from upper left, the HFJV adapter, the view down the bore of the bronchoscope with adapter properly oriented, the adapter properly attached, and the adapter rotated 45 degrees.

Another important point in HFJV is that the geometry of the jet is critical to its efficiency. The jet should be delivered through a narrow aperture, and this must be aligned with the trachea. When the jet is directed at a 90-degree angle to the long axis of

the trachea, the jet is totally ineffective. Even a 5-degree angle reduces efficiency considerably. This can be a problem during rigid bronchoscopy with devices such as the Efer-Dumon Bronchoscope (Efer Endoscopy, La Ciotat, FR), as it is all too easy to rotate the jet connection to the side arm of the bronchoscope, as illustrated in Figure 23.2.

In summary, practitioners often find HFJV a daunting mode of ventilation, as the normal monitoring modalities are unavailable. With a fuller understanding of the physics and physiology of HFJV, it is possible to become comfortable with this modality—but one should never become complacent.

## TAKE HOME POINTS

- High-frequency jet ventilation is a standard of airway management in laryngeal and tracheal procedures. Anesthesiologists should be able to use it comfortably and efficiently.
- Inspiration is via a unidirectional jet of gas traveling down the airway. Exhalation is passive.
- Carbon dioxide is removed even though individual delivered breaths are less than the dead space. Stacked breaths increase lung volume above closing capacity.
- The geometry of the jet is critical, it should be directed as precisely as possible along the long axis of the trachea.

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# Know How to Perform a Cricothyroidotomy

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Management of the airway has a well-defined algorithm. Securing the airway surgically is part of that algorithm (down at the bottom!). Obtaining surgical access is usually done in the operating room, or in an intubated patient in the intensive care unit under controlled circumstances. In the past, surgeons were everywhere 24/7 so it was rarely necessary for a nonsurgeon to perform a procedure to gain control of the airway in an emergent fashion. However, the advent of more restricted residency work hours and the need to do more cases to generate the same billing income has spread surgeons "more thinly" than in the past. Many services now have night floats that cover many services or take home call. Thus the ability to obtain a surgical airway, performed by surgeons, may be delayed.

A cricothyroidotomy is a method of obtaining a surgical airway that differs from the classic tracheostomy and is considered by many surgeons to be the preferred technique for initial emergent surgical airway management in many different circumstances. The cricothyroid membrane is generally easy to locate and is fairly avascular. Because cricoid cartilage chondritis, with the unfortunate sequelae of subglottic stenosis or voice change, can develop after cricothyroidotomy, revision to a conventional tracheostomy, usually at the second or third tracheal ring (which involves exposing and separating the strap muscles and dividing the thyroid isthmus), is generally performed within 24 to 48 hours. When converted to a traditional tracheotomy, the long-term morbidity is minimal. The cardiac literature demonstrates that in controlled circumstances, airway complications after a planned cricothyroidotomy are minimal. In the emergent situation, most otolaryngologists would not revise the cricothyroidotomy if it is to be removed within 48 hours.

The most important step in performing a cricothyroidotomy successfully is making the decision to do one. The second most important step is remaining calm, collecting the instrumentation, and proceeding in a controlled fashion. The authors' opinion is that most anesthesiologists have the technical skills necessary to facilitate an "emergency surgical airway" via cricothyroidotomy, while a different anatomy, the Seldinger technique for vascular access, is directly translatable into this procedure. Although a

Seldinger technique is often taught for cricothyroidotomy, a recent study cited on the American Society of Anesthesiologists website (see Suggested Readings) demonstrated that the Seldinger technique, as performed by medical students with commonly available commercial kits, did not establish an airway as frequently as they did with an open surgical technique.

The steps used by airway surgeons in performing emergent cricothyroidotomy are as follows:

) Position yourself on the side of the bed where your dominant hand is cephalad (i.e., if you are right handed, you will be standing by the patient's left shoulder).

) You do not need to prep the neck; you will be entering the airway, a "clean-contaminated" area.

) Palpate the cricoid membrane—this is located above the cricoid cartilage and below the thyroid cartilage. **It is the exact location where transtracheal lidocaine is injected for anesthesia for an awake airway procedure.** The ubiquitous ultrasound may be used to identify the cricothyroid membrane if the anatomy is "complicated."

) Ask for a no. 15 blade, although in an emergency any scalpel will suffice.

) Plan for a midline incision, ~4 cm long and have retractors ready to enhance visualization.

i. With your dominant hand moving from the foot to the head, use the belly of the blade to make a longitudinal incision in the midline, ~4 cm long superficial to the cricoid membrane.

ii. Take care to stay in the midline. Large anterior thyroid veins run on either side of the midline and can cause bleeding sufficient to completely obscure the field.

iii. Make a generous incision. A long incision allows the tissues to "gap open" and will make visualization of the trachea easier.

) Apply enough pressure to the blade to reach the level of the cricoid membrane with two passes.

) If the person is obese, ask for instruments to retract the tissue. You will need two (one for each side). Army–Navy, thyroid retractors, or vein retractors are all acceptable choices.

) Once at the level of the cartilage, palpate for the cricoid membrane.

) When the cricoid membrane is located, use the scalpel to "poke through" the cricoid cartilage in a vertical fashion. Once you have entered the airway, maintain an instrument in the airway—the scalpel, a Yankauer suction, or the endotracheal tube.

0) You will know you are in the airway when there is the sound of air moving in and out of the neck and burbling from the secretions. Take care not to have your face too close to the operative field when performing this step so as not to have a splash exposure.

1) Without removing the blade, turn it 90 degrees and incise 0.5 cm in each direction to

widen the opening.

2) Without removing the blade, insert a rigid suction into the trachea to remove the tracheal secretions. Remove the scalpel and pass it off of the field. Retract the lower edge of the incision you have just made toward the feet with the suction. Do not take the suction out of the airway at any time before the endotracheal tube is placed. The incision will "close shut" and you may have difficulty relocating the site where you entered the airway due to coughing, bleeding, and tracheal secretions.
3) Have an assistant bend the tip of a 6.0 cuffed and styletted endotracheal tube to an approximate angle of 75 to 90 degrees.
4) With your now free dominant hand, insert the tube with a curving motion in the caudad direction until the cuff is a few centimeters below the incision.
5) Remove the stylet and check for good air flow and return of $CO_2$ with gentle ventilation per standard anesthesia protocol—aggressive ventilation through a misplaced endotracheal tube can dissect tissue planes with air and obscure the anatomy.
6) **Do not let go of the tube until it has been sewn into place.** The tube can be secured with tape if you wish to wait for a surgeon to secure it with sutures. If you are comfortable suturing the tube in place, do so with a 0 silk suture. Gauze can be lightly placed over the wound. A surgical consult can be called to assess if the wound should be closed and whether to convert to a formal tracheotomy in the operating room. Often the same incision can be used.
7) If at any stage bleeding is experienced, do not use cautery. There is a risk of igniting the surrounding oxygen and putting the patient and staff at extreme risk. The wound can be packed with gauze or surgical. Pressure will control the bleeding.
8) Do not be concerned about the aesthetics of the incision or where the tube actually entered the airway or the comments of colleagues. Remember, this is a lifesaving maneuver and the scar and risk of permanent damage to the airway is small. The scar can be repaired. Airway complications can be managed when the patient is seen by the otolaryngologist within 48 hours and are minimal. Your colleagues will undoubtedly be polite as they know that an anesthesiologist performing a cricothyroidotomy is the very definition of an emergency situation.

## TAKE HOME POINTS

- Remember that "otomy" means to cut or open, "ostomy" means to cut and bring to the surface. A cricothyroidotomy simply means to cut the cricothyroid membrane for the purposes of inserting a temporary airway, usually an endotracheal tube. "Tracheotomy" and "tracheostomy" are sometimes used interchangeably, although in the most correct usage, the "tracheotomy" is the procedure to make the tracheal

airway and the tracheostomy is the opening or hole in the trachea, with its accompanying airway device.

- If you are an anesthesiologist, you can do a cricothyroidotomy! The two most important things to do a successful emergency cricothyroidotomy are to first recognize and decide that you need to do it. And then to remember that it's performed at the same anatomical location as transtracheal lidocaine injections.
- Unlike a transtracheal injection of lidocaine, it's done in two layers—first make a longitudinal incision of superficial soft tissues, cutting from the foot to the head, about 4 cm long.
- After retraction of the tissues, the scalpel blade is inserted longitudinally into the airway, then turned 90 degrees.
- A suction catheter is then inserted in the opening. Leave this in place until a 6.0 styletted endotracheal tube is placed. Put a 90-degree hook on the end of the endotracheal tube before placing it into the airway. Use the standard technique to verify placement in the airway and return of $CO_2$.
- Do not let go of the endotracheal tube until it is sutured in place. Ventilate gently.
- Otolaryngology will revise the incision and airway instrumentation as soon as feasible after the emergent airway is secured. Scars, even to the airway, can usually be adequately managed.

## Suggested Reading

Available from http://anesthesiology.pubs.asahq.org/article.aspx?articleid=2528137. Accessed May 19, 2017.

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# Don’t Make the Mistake of Thinking That a Tracheostomy Is a Guaranteed Airway

Steven L. Orebaugh, MD

Tracheostomy tubes are ubiquitous in anesthesia practice, and it is important to understand what may go awry with them. A number of complications should be borne in mind when caring for patients with these devices. And besides the problems listed below, the first and biggest mistake you can make is to take your mind off the need for airway vigilance always.

) Obstruction of the tube
) Foreign body lodged in the tracheostomy tube
) Loss of airway with removal of the tracheostomy tube
) Hemorrhage
) Other, nonemergent complications

## Tracheal Tube Obstruction

Obstruction of the tracheal tube may occur from a variety of different causes, including secretions, clots, granulomatous tissue, or the wall of the trachea itself. One of the most common causes is obstruction of the lumen by inspissated secretions, which may gradually lose their aqueous component through evaporation, and become dried, thick, and viscous. Unless the tube is periodically cleaned, the buildup of such secretions may lead to a subtotal, or even complete, lumen occlusion. This can be prevented with attentive nursing and hygiene, including frequent cleaning of the tube, use of humidified air or oxygen, use of tracheostomy tubes with an inner cannula which can be removed for frequent cleaning, and prompt measures to limit or stop bleeding, so that clots do not accumulate in the tube or airway.

Not uncommonly, tracheal erosion or irritation leads to minor degrees of bleeding in the airway, clots from which can also contribute to obstruction of the tube. Another potential issue is the formation of granuloma tissue in the trachea, due to mucosal irritation from the distal portion of the tracheostomy tube, which may result in symptoms of obstruction due to tracheal stenosis.

Tracheostomy tubes may become obstructed in the immediate postoperative period for a variety of reasons, including tube misplacement or inappropriate sizing, which can cause the tip of the tube to lie against the posterior tracheal wall with resultant "ball-valve" effect.

Tracheostomy obstruction may present with dyspnea, increased work of breathing, and also high peak inspiratory pressures if the patient is receiving positive pressure ventilation. Breath sounds may be reduced in proportion to the decline in tidal volume. Patients breathing spontaneously will develop abnormal inspiratory and expiratory noise which will coincide with airflow through the restricted lumen. Passage of a suction catheter through the tube at the bedside can be both diagnostic and therapeutic. The obstruction will potentially obstruct or prevent its advance into the trachea.

Intervention for obstruction of a tracheostomy tube depends upon the severity. In milder forms, irrigation with saline and suction with a catheter may serve to reduce the buildup and increase the patency of the lumen. Removal of the inner cannula permits the necessary cleaning, while maintaining ventilation. If the tract is well established and there is no danger of losing the stoma for reinsertion, the tracheostomy tube may be removed, a substitute placed temporarily, and the obstructed tube soaked and cleansed until the lumen is clean. In more acute settings in which the process is well advanced, the patient may be in extremis on presentation with hypoxia and hypercarbia before the process is suspected. Attempts to assist ventilation with bag-valve apparatus will generate high resistance and pressures, as well as inadequate tidal volumes. If an inner cannula is present, its removal may permit ventilation with a resuscitation bag. Attempting to pass a suction catheter through the obstructed tube will support the diagnosis, but often will fail to resolve the obstruction, as passage of the catheter will not be possible. The tracheostomy tube must then be rapidly removed and replaced with a clean one if maturation of the tracheostomy has occurred, or the patient may be ventilated and/or intubated from above in a rapid fashion to provide oxygenation and ventilation, if possible.

## Foreign Body in Tracheal Tube or Airway

Foreign bodies introduced into a tracheal tube may become lodged within relatively easily, either accidentally, or if placed there intentionally, often in an attempt to clean the airway. Soft bodies, such as vegetable matter, may occlude the lumen in much the same manner as mucus or clot, and the patient will present in the much the same fashion. However, attempts to push on or dislodge the body with a suction catheter or other instrument may result in its inward passage, producing a tracheal or bronchial foreign body. Sometimes, the body will break up and can be retrieved with irrigation and suctioning; if not, retrieval may require more invasive management with rigid or

flexible bronchoscopy.

However, when the body is hard or firm in nature, such as a cotton-tip applicator, it may not completely occlude the airway. Nonetheless, these objects can be very difficult to retrieve, and there is a risk that, while attempting to retrieve it, the body will be dislodged into the airway, requiring bronchoscopy for removal. Given these concerns, it is preferable to remove the tube, replacing it as necessary with another (or managing the airway from above if the tracheostomy is immature), and removing the foreign body when the tube is outside of the patient. If the foreign body is lodged within the airway, but adequate ventilation is possible, the tracheal tube can be left in place, and the patient managed in the operating room, where the object can be extracted under controlled conditions.

## Loss of Airway With Tracheostomy Tube Removal

In a patient with a tracheostomy tube, one of the most feared complications is that the tube would be inadvertently removed before the tract for the tracheostomy has sufficiently matured. The tract between the skin and the trachea is usually established in 5 to 7 days, and matures in about 10 days. Early removal or change of the tracheostomy tube predisposes patients to this potentially life-threatening complication. When a tracheal stoma is well developed and mature, replacement of the tube is usually not difficult. However, when the tracheostomy has been recently placed, the tract will likely be immature, and the passage may not be easy to find when the tube has been removed. Airway loss may occur when the tracheal tube is removed, either unintentionally or with purpose in the postoperative period. Caution is therefore always indicated during the initial change or removal of the tube.

Under these circumstances, patients will likely present with dyspnea, tachypnea, and hypoxemia. If the tube is clearly out of the airway the diagnosis is simple, but in some cases the tube may remain beneath the skin or be in a “false passage,” though not in the airway. Breath sounds will be reduced or nonexistent, and the loss of a patent airway tube may lead to life-threatening consequences, as replacement may be difficult and delayed. When the tube is clearly not in the airway, and no ready tract exists for its re-insertion, one should manage the airway from above, with either bag-mask ventilation or direct laryngoscopy with endotracheal tube placement. It is important to note that some patients with tracheostomy would have undergone the procedure because of abnormal airway anatomy, and therefore will present a serious challenge. Others would have undergone the procedure because of failure to wean from mechanical ventilation, and for them intubation through the traditional route of the larynx should be less problematic.

Facial trauma, surgical removal of the larynx, or a large air leak through the stoma

may make face-mask ventilation ineffective in those who have undergone tracheostomy. In any of these situations, ventilation through the stoma itself with a face mask may be a possible alternative. A small pediatric mask should be utilized, placed over the stoma with an attempt to create a seal.

Appropriate tools for airway management and tracheostomy placement must be available when the tube is to be replaced, including tubes smaller than the one initially placed and the instruments on a tracheostomy tray, such as a dilator and a trach hook, if these are available. In addition, surgical backup by an ENT surgeon is preferable. Supine position, with a degree of neck extension, will serve both to open the tract and improve visualization. If present, pulling on the traction sutures may be all that is required to open the tracheostomy sufficiently to place the tube. If it is not possible to visualize the opening, gentle attempts to find the tract digitally may be successful. A tube one size smaller than the original should be placed. If the tract cannot be visualized or found, other options include placement of a bougie or the use of a fiberoptic scope to find the airway. As in any tracheostomy-related emergency, if hypoxemia or deteriorating conditions do not permit rapid establishment of an airway through the stoma itself, then the airway should be approached with ventilation and tracheal intubation via the oral route. The orotracheal tube must extend below the level of the tracheal incision and the cuff adequately inflated to seal the trachea, or loss of gas through the stoma will occur, leading to inadequate ventilation.

There are several factors that may predispose to loss of the tracheostomy tube. These include incorrect initial placement of the tube, a poorly fitting tube, inadequate securing of the tube, vigorous coughing, and a large neck with plentiful subcutaneous adipose tissue.

## Hemorrhage

Hemorrhage may occur intraoperatively or immediately postoperatively relating to either surgical trauma or oozing from a coagulopathic state. This may be either as obvious external blood loss or cough productive of bloody secretions from the tracheostomy tube. If blood loss is severe, tachycardia and hypotension may occur due to hypovolemia. Such surgical bleeding is usually apparent immediately after surgery and will be addressed by the surgical team. Minor hemorrhage can be treated with compression or packing. If this fails, return to the operating room may be necessary for cauterization or for ligation of vessels.

Later bleeding may be due to granulation tissue, trauma from suction or from changing the tracheal tube, progression of underlying neoplastic or inflammatory conditions, and fistula formation. The incidence of postoperative hemorrhage after tracheostomy is approximately 3%, and roughly 10% of these cases are due to

tracheobrachiocephalic artery fistula. A fully developed fistula, when opened, will cause exceedingly brisk bleeding, which rapidly becomes life threatening. Both hypovolemia and the blood pouring into the airway require rapid and aggressive therapy. Immediate overinflation of the tracheostomy cuff is recommended to provide a tamponade of the bleeding artery, providing a measure of control until the patient can be taken emergently to the operating room for definitive surgical therapy. If this measure is not effective, a cuffed endotracheal tube can be inserted, with its tip placed below the level of the bleeding source to stop blood from entering the lungs. In addition, the tracheostomy tube should be removed with firm digital pressure exerted on the bleeding site to provide control of hemorrhage. Placing the patient in a position that allows drainage of the blood as well as frequent suctioning are important aspects when brisk hemorrhage occurs.

The severity of bleeding from the tracheostomy site will dictate the interventions and the urgency of management. Vigorous hemorrhage will require a return to the operating room for assessment and control. In addition, volume resuscitation, blood products, or coagulation products may be required depending upon the cause of the bleeding and how quickly it can be controlled.

## Chronic Complications

Several adverse occurrences may occur well after tracheostomy, which are less likely to require urgent management. Long-term maintenance of an indwelling tracheostomy tube may result in mucosal irritation, inflammation, scarring, and tracheal stenosis. Colonization of the tracheal wound is quite common, but occasionally frank infection may occur. Swallowing dysfunction is very common after tracheostomy and this may predispose to poor nutrition or to aspiration of gastric contents with resultant pneumonitis. An ill-fitting tracheostomy tube may produce excessive pressure on the posterior wall of the trachea which can lead eventually to mucosal erosion or even to the development of an tracheoesophageal fistula.

### TAKE HOME POINTS

- When a tracheostomy tube becomes acutely obstructed, removal of the inner cannula will permit cleansing and reestablishing a patent lumen while still allowing ongoing gas exchange.
- If a foreign body becomes lodged in a tracheostomy tube, it may be removed at the bedside if readily accessible and if ventilation is not impaired; otherwise this situation should be addressed in the operating room.
- Management of a tracheostomy tube which is inadvertently decannulated depends on

the maturity and patency of the underlying tract; if no tract is evident (or palpable), attempts to reinsert the tube should be abandoned in favor of translaryngeal intubation from above.

- Postoperative hemorrhage after tracheostomy is often minor and can be managed with simple compression or packing at the bedside; however, severe hemorrhage, such as from a fistula, requires protection of the lungs, emergent attempts at tamponade, and return to the operating room for surgical control.

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# Helium for the Compromised Airway—You Have to Understand the Principles and Properties but We've Seen Some Amazing Saves

Anne Elizabeth Kamarchik, MD, Theresa A. Gelzinis, MD, and J. Mauricio Del Rio, MD

A 22-month-old girl began coughing while eating some sunflower seeds. Shortly thereafter, she appeared to be gasping for air. Her mother performed back blows and called for an ambulance. In the emergency department she was awake, alert, and sitting forward with obvious stridor, increased work of breathing, frequent coughing, and drooling. The patient was transported emergently to the operating room for airway management. When you arrive, her vital signs are blood pressure 119/76 mmHg, respiratory rate 66 breaths/min, heart rate 160 beats/min, and pulse oximetry 90% with some blow-by oxygen. Examination of the chest reveals mild retractions and faint bilateral wheezing. While awaiting the arrival of the ENT surgeon, the patient has intermittent episodes of perioral cyanosis, repetitive coughing, and worsening stridor. How would you manage this patient?

Since 1934, when helium was first described as therapy for upper-airway obstruction and asthma exacerbation, it has been advocated for the treatment of a wide variety of respiratory conditions.

## Physical Properties of Helium

Helium is a colorless, odorless, tasteless, inert, monatomic element that exists as a gas except in extreme conditions. As a consequence of its low atomic weight (4 g/mol), the density of helium is the lowest of any gas except hydrogen; unlike hydrogen, it is nonflammable and thus safer for medical use. Helium's low density allows $CO_2$ to diffuse five times more rapidly through a helium–oxygen mixture than through air or oxygen. Being biologically inert, helium has no direct pharmacologic effects and has no intrinsic bronchodilatory or anti-inflammatory properties. For the same reasons, it has

no known toxic effects, even when used for extended periods of time.

## Heliox

Heliox is a mixture of helium and oxygen gases. Standard heliox cylinders contain 80:20 (He:O ratio) heliox, though heliox is also available in 70:30 and 60:40 mixtures. Commercial-grade heliox is available in H-size cylinders, which contain approximately 1,200 L of noncondensed gas at approximately 2,200 psi. The need for supplemental oxygen in patients requiring heliox therapy often limits the helium concentration that can be administered.

## Physics of Fluid Flow With Heliox

The behavior of a fluid in flow is related to two intrinsic properties of the fluid: density and viscosity. The density of helium is 0.179 g/L, which is 70% to 80% less than the density of oxygen or air. Viscosity is an internal property of a gas, which causes resistance to flow. A fluid with high viscosity strongly resists flow.

Under normal circumstances, gas flow in many parts of the respiratory tract is largely orderly, known as laminar flow and follows the Hagen–Poiseuille law. This law states that the fluid flow rate (Q) through a straight tube of uniform bore is proportional to the pressure gradient (ΔP) and the fourth power of the radius (r), and is related inversely to the viscosity of the gas (μ), and the length (l) of the tube:

$$\dot{Q} = \frac{\Delta P \pi r^4}{8 \mu l}$$

Note that laminar flow is viscosity dependent, density independent, and highly dependent on radius. Because the viscosity of helium, oxygen, and air is similar and laminar flow velocity is independent of density, heliox has no effect on areas of laminar flow.

Turbulent flow occurs in constricted passages and is governed by a different law:

$$\dot{Q} = k\sqrt{\frac{\Delta P}{\rho}}$$

Compared with laminar flow, turbulent flow is chaotic and less efficient. Flow increases with the square root of the pressure gradient, so quadrupling the pressure gradient merely doubles the flow. Decreasing the density (ρ) will also increase the flow. As flow velocity decreases and/or airway resistance increases, there is a critical level at which the flow pattern changes from the laminar to turbulent. This type of flow

(laminar vs. turbulent) is defined by the Reynolds number (Re):

$$Re = \frac{VD\rho}{\mu}$$

where V represents the mean velocity of the gas, D represents the airway diameter, ρ represents the gas density, and μ is the viscosity of the gas. The Reynolds number is the ratio of inertial forces (density dependent, viscosity independent) to viscous forces (viscosity dependent, density independent). Laminar flow occurs at low Reynolds number (Re <2,100) when viscous forces are dominant and is characterized by smooth, constant fluid motion. Turbulent flow occurs at high Reynolds number (Re >4,000) and is dominated by inertial forces, producing random eddies, vortices, and other flow fluctuations. Transitional flow lies between these values and displays qualities of both types of flow.

Replacing nitrogen with helium decreases the density of the gas mixture as well as the Reynolds number, making the flow more likely to be laminar, which improves the flow efficiency and reduces the respiratory effort. Extremely turbulent flow patterns exist when a gas flows through an orifice, such as an edematous glottis where the flow rate becomes proportional to the gas density according to the Bernoulli equation:

$$Q = (2\Delta P/\rho)^{1/2}$$

Therefore, by using helium as the carrier gas, heliox will reduce the density of the inspired gas and will provide a higher flow rate at the orifice, even if the flow remains turbulent. This results in a lower resistance to gas flow, allowing for increased bulk flow through high-resistance airways and converting some or all of the turbulent flow to laminar flow. Consequently, there is increased oxygen flow and decreased work of breathing.

Air flow patterns in the pulmonary system are products of the physical conditions in the airway (e.g., diameter, anatomic shape, branching, and smoothness of airway lining) and the composition of the inhaled gas. Air flow in the lung periphery is primarily laminar because of the large cross-sectional surface area through which the gas flows. Conversely, air flow in the larger upper airways is turbulent, with relatively high flow and relatively small cross-sectional surface area. The flow characteristics in the airways may also vary depending on the inspiratory and expiratory flow rates. During normal breathing, a transition from the turbulent to the laminar flow occurs from the trachea to around the second generation of bronchi. However, in patients with airway obstruction, turbulent flow occurs randomly and more frequently, even at low respiratory and flow rates. This leads to increased work of breathing. In patients with

increased airway resistance, heliox administration will reduce the resistance to flow, which will lead to decreased work of breathing.

## Administration

Helium has a very high diffusion coefficient, which requires it to be stored in special, tightly sealed containers. In order to achieve a sufficient helium concentration (>50%) to gain maximal advantage from the helium, the administration system needs to be "helium tight." Therefore, the most effective heliox systems are closed systems. The system should also be high flow to minimize the rebreathing of low-oxygen gas, with sufficient flow to meet or exceed the patient's minute volume and peak inspiratory flow, and to minimize dilution with ambient air. Flushing a high flow of heliox into the patient's airway is expensive and can be wasteful. Hence, the delivery method should include a reservoir and an on-demand delivery system that minimize total flow and helium requirements.

Heliox can be used in patients who are breathing spontaneously, but also in the settings of both invasive mechanical ventilation (e.g., with tracheal intubation) and noninvasive mechanical ventilation. The beneficial respiratory effects of heliox include a reduction in transpulmonary pressure requirement (and thus work of breathing), increases in tidal volume, improvement in the homogeneity of gas distribution, improvement in the elimination of $CO_2$, and improvement in the delivery of aerosolized medications.

In many centers, heliox may be part of the pipeline supply of medical gases to the ICU or to the OR. In the OR, the administration may be titrated with oxygen via a specific heliox flowmeter in the anesthesia machine, assuming the flowmeter has been calibrated for such a mixture. Large academic centers will usually schedule airway cases in rooms with the capability to deliver heliox via the anesthesia circuit. In the ICU setting where pipeline supply of helium may be available, respiratory therapists typically connect a helium regulator and blender to the oxygen flowmeter and administer the selected mixture based on clinical needs (of note the pipeline supply is often a 80:20 mix already). Similarly, when administering helium from a tank, the appropriate helium regulator with an oxygen blender should be used. Of note, when used in this manner a conversion may be necessary to calculate the total flow delivered to the patient, as the oxygen flowmeter itself will underestimate the actual volume delivered secondary to the differential density between the two gases as the oxygen flowmeter itself is not calibrated for helium.

## Possible Clinical Applications

- Upper-airway obstruction

- Postextubation stridor
- Croup
- Bronchiolitis
- Asthma exacerbation
- Chronic obstructive pulmonary disease (COPD) exacerbation
- Pulmonary function testing

When used for these purposes in different clinical trials, heliox therapy has been shown to relieve stridor, reduce the work of breathing, and reduce respiratory distress to act as a therapeutic bridge to allow time for definitive treatments to become effective; to prevent intubation in patients with impending respiratory failure and decrease the need for intubation or reintubation in perioperative settings; and to shorten the length of perinatal ICU stay in infants with bronchiolitis. Of note, heliox is of particular use in acutely ill patients, as it has no significant hemodynamic effects.

## For Upper-Airway Obstruction and Stridor

Stridor is a case of orifice flow and the low density of heliox mixtures improves the flow at the orifice. The literature from pediatric burn centers related to children with postextubation stridor reports improved outcomes. Specifically, such studies note less respiratory distress and fewer episodes of reintubation in patients who received early heliox therapy when they showed signs of postextubation stridor or retractions, than in those patients in whom heliox therapy was somewhat delayed. While data does not conclusively point to the routine use of heliox for this indication, it may certainly have a role in managing the acute upper-airway obstruction.

## For Croup and Bronchiolitis

Viral upper respiratory tract infections are a common cause of pediatric respiratory distress where they reduce the radius of lengthy segments of the tracheobronchial tree. However, this patient population is often hypoxic and therefore is unable to receive the low fractional inspired oxygen concentration required with heliox mixtures. At present, while heliox presents an alternative therapy for the management of moderate to severe croup, most sources do not recommend this as a routine therapy.

## For Asthma Exacerbation

Heliox can be effective for patients with severe air flow obstruction. The beneficial effects seem to be most efficacious when heliox is used within 24 hours of the onset of symptoms, as early use may decrease dyspnea and improve gas exchange especially while implementing conventional therapies which may require hours for full effect (e.g., steroids). Heliox can be used as a temporizing measure to prevent intubation and has a

relatively safe treatment profile. Usually, clinical benefits of this therapy are rapidly evident.

## For Severe COPD

Heliox may improve alveolar ventilation and gas transfer (decreasing $PaCO_2$) as well as reduce the need for intubation. Heliox should be considered in individual cases when intubation is required, but would be undesirable. However, wide-scale use of heliox cannot be recommended based on clinical evidence.

## New Avenues in Clinical Helium Use

Unlike the noble gas xenon, helium does not possess any anesthetic properties. However, studies performed in animal models and in limited human paradigms have shown potential clinical applications related to the effects of heliox on several organ systems. Its utility may not simply be limited to the management of obstructive airflow disorders in the future.

## Risks of Heliox Use

### Hypoxemia/Anoxia

There is a possibility of delivering a gas mixture that contains <21% oxygen. This risk is reduced by administering only heliox that contains at least 20% oxygen. The concentrations of both helium and oxygen in the cylinder should be verified prior to its use. The use of an oxygen analyzer in line with the gas output provides monitoring to prevent hypoxemia. There have been reports of hypoxia during heliox administration in preterm infants who have a history of bronchopulmonary dysplasia and subglottic stenosis. This could be related to the reduction of lung volume and the increased intrapulmonary shunt secondary to their disease.

### Volutrauma/Barotrauma

Flow of heliox is faster than that of air or oxygen. Consequently, when using a flow meter calibrated for oxygen or air, a correction factor (based on the helium concentration) must be applied to correct for the difference in flow rate. The heliox correction factors are generally rounded off to 1.4 for 60:40, 1.6 for 70:30, and 1.8 for 80:20. Thus, when an oxygen flow meter delivering 80:20 heliox reads 10 L/min, it is actually delivering 18 L/min. If a system delivers more than the set volume, there is a risk of volume-induced injury, pressure-induced injury, or hypocarbia. This is of particular concern with closed systems that are not designed for heliox administration.

### Inadequate Delivery of Aerosolized Medications

Poorly adjusted flow of heliox in a nebulizer can result in a subtherapeutic dose or can increase the dose delivered to the lungs above the intended levels.

### Hypothermia

Hypothermia has been associated with hood administration of heliox to infants. Heliox has a high thermal conductivity with consequent risk of hypothermia when the gas temperature is <36°C, especially when it is administered for long periods. The risk of hypothermia can be avoided with adequate warming and humidification of the inhaled gas.

## TAKE HOME POINTS

- Heliox is clearly useful in patients with upper-airway obstruction.
- It can relieve stridor, reduce work of breathing, and reduce respiratory distress. We have seen some fairly amazing clinical outcomes with the use of heliox.
- It may decrease the need for intubation or reintubation in perioperative settings.
- It can allow time for other interventions or therapies to become effective.
- Heliox must be administered with devices designed for that purpose. If you don't know, take the time now to talk to the respiratory therapists and hospital administration about what heliox resources are available and how you access them. And certainly always do this when starting practice in a new location.
- Definitive clinical evidence is needed to elucidate its role; however, there is an extensive range of possible applications for this gas and further studies are needed to capture the clinical diversity of such therapy.

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## SECTION II

# LINES and ACCESS

27

# Introduction

Brian T. Gierl, MD and Catherine Marcucci, MD

The safe and efficient placement of lines and access and then managing them carefully and with vigilance is one of the cornerstones of the practice of anesthesiology. As we state elsewhere in this book, it is one of the reasons we get up and come to work every day.

We once had a faculty member who referred to venous lines as "lifelines" which, if you think about it, could not be more true. As you were getting ready to turn a patient, he would inquire, "Who is watching the lifelines?" This simple wordplay instilled an ongoing and healthy vigilance and respect for the patient's access that is still with us today.

In updating these chapters, we worked from the position that no line is trivial, either for the patient to receive or you to place. Even a "simple" peripheral IV to start a case calls for concentration on the part of the provider so that it is done quickly, quietly, and confidently and with minimal discomfort. More advanced lines, of course, will require more technical skill and knowledge of the physiology. But regardless of how "fancy" or how invasive, every line mandates adequate site selection, careful preparation for insertion, safe and effective taping or suturing, and safe use.

When revising the chapter on pulmonary artery (PA) catheters, we first compared notes among ourselves as to whether this granddaddy of invasive lines is still relevant for today's anesthesia provider. Because we are rather a large group of authors and editors, we received a range of opinions, which was somewhat specific to institution and type of surgical case. Some of us do not use them as frequently as we once did and/or are now practicing in locations where other methods of measuring cardiac output are now being used. On the other hand, the PA catheter is still widely used for heart failure and transplant patients and in the CVICU. We discuss this at greater length in the chapter itself.

On a final note, we remind our readers that IV placement seems to be something that patients remember and can recount in some amount of detail—who put it in, whether that person "knew what they were doing" and how many tries it took—even if they remember little else about the entire perioperative period. We have even heard the

word “bozo” used from time to time by patients when describing previous IV placement flails. Work as hard as you can to get and maintain expertise in catheter placement—hopefully you will never look like a clown in front of patient, their family, the surgeon, or worse … the coroner.

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# Remember That the IV Start Is Your First Chance to Make a Favorable Impression on the Patient

Christina Stachur, MD MPH, Hassan Mohamed, MD, and Catherine Marcucci, MD

Intravenous access is a crucial part of anesthesia care, and placement and management of lines are important skills for an anesthesiologist. Virtually all anesthetics require some degree of intravenous (IV) access, whether it is for induction of general anesthesia, administration of medications, fluid resuscitation, or blood sampling.

Whether IV access is obtained in the awake patient (such as for induction of general anesthesia in adults, regional anesthesia, or conscious sedation), or in the anesthetized pediatric patient after inhalational induction, it is imperative that the anesthesiologist be both technically proficient and display a professional comforting report with the patient.

Peripheral IV placement can be one of the most challenging procedures in anesthesia, especially for beginners. Some general points for **optimizing your environment and starting peripheral IVs**:

- Introduce yourself to the patient and let them know what you will be doing. This is especially true if you are just placing an IV for a colleague, and the patient has not met you yet as a part of the medical team. You can start the most painless well-functioning IV, but the patient's experience will be less than positive if you are flippant, rushed, or gruff.
- The initial needle stick can be very unpleasant for some people and this is the part of their procedure that they are most anxious about. Warn them before you attempt IV placement, so the patient is not startled.
- When available, attempt to anesthetize the skin before starting the IV. This can be accomplished with IV lidocaine injected under the skin through a very small gauge needle (29G or insulin needle), local anesthetic cream (EMLA® cream; lidocaine 2.5%; and prilocaine 2.5%), or an instant topical anesthetic skin refrigerant (Pain Ease®).
- Choose a location that is convenient for you and the surgeon. For example, don't place an IV in the right hand if the patient is having a right-sided carpal tunnel release.

Consider carefully before starting an IV in the foot of a patient with diabetes or significant soft tissue changes in the lower extremities. Some anesthesia providers will do it, but the podiatrists tend to advise against it.

- Use a tourniquet to engorge veins. Other techniques for improving vein visibility include: encouraging the patient to exercise their extremity against resistance for 20 seconds, "hang" the extremity in the dependent position, and use of an instant hot pack. To avoid cutting off arterial flow, do not make the tourniquet too tight. **The person who puts the tourniquet on the patient is responsible for removing it—make sure this happens!** Be especially careful if you have put a tourniquet on the lower extremity or in an anesthetized patient—these tourniquets tend to be "forgotten" more often. Severe complications such as necrosis requiring surgery and rehabilitation, have occurred from tourniquets inadvertently left on patient's extremities.
- Flush your IV tubing before connecting it to the catheter to avoid letting air into the patient's circulation. This is especially important in cardiac and pediatric cases—even tiny bubbles can have catastrophic effects.
- Have gauze, tape, and dressings readily available and within your reach before you begin placing the IV. You don't want to lose a newly placed IV simply because you are fumbling with supplies. Have someone assist you whenever possible.
- If the patient shows signs of being a difficult stick, ask them if they can recommend a site.
- Only one person sticks the patient at a time!
- In seated patients, always watch for vasovagal reactions. These tend to occur in the youngest and healthiest patients.

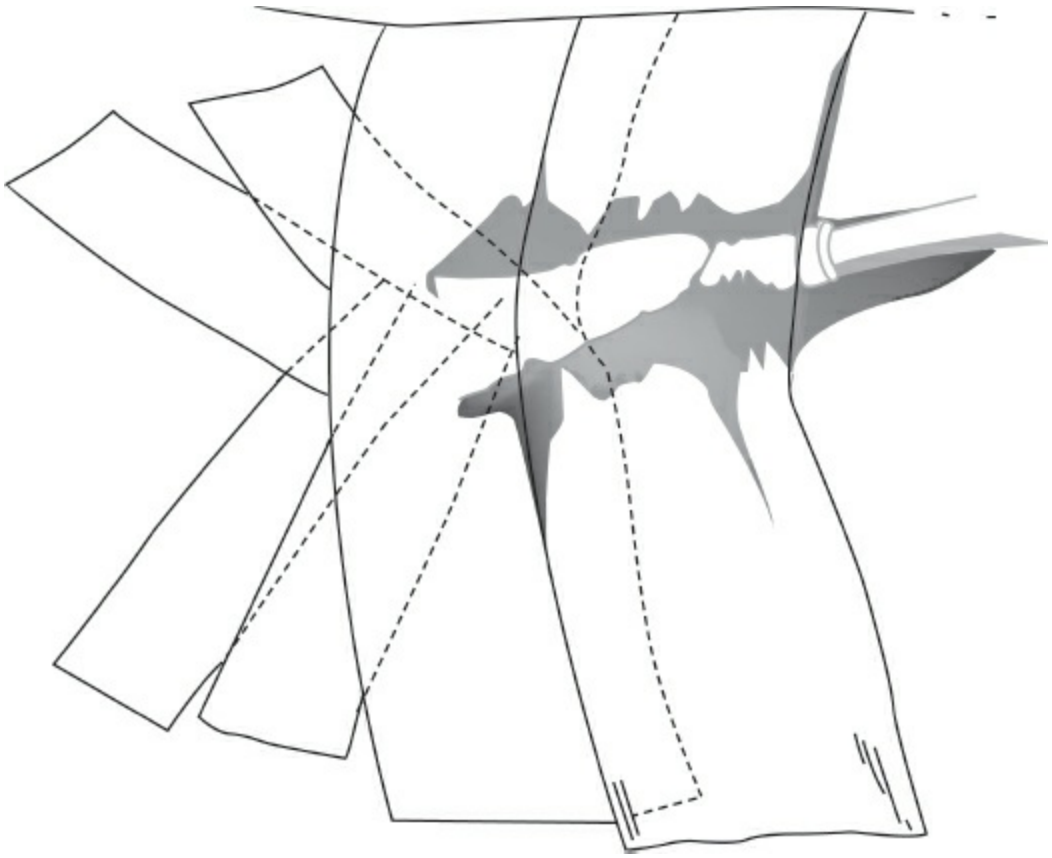

**Figure 28.1.** Preferred taping method. (Modified by permission from Springer: Patel N, Smith CE, Pinchak AC, et al. Evaluation of different methods of securing intravenous catheters: measurement of forces during simulated accidental pullout. Can J Anaesth. 1995;42(6):504–510. Copyright © 1995 Canadian Anesthesiologists.)

After you have created an environment that is conducive to placing IVs, the next challenge is to properly execute and thread the IV. Some tips for successful **placement of peripheral IVs** include:

- Advance your needle far enough that the catheter is within the vein. Remember that a flash of blood in the angiocath indicates that the needle has punctured the wall of a vein, but the catheter might still be outside. This is especially true in larger-bore IVs, in which there is 2 to 3 mm between the tip of the needle and the tip of the catheter.
- For superficial or "rolling" veins, first puncture the skin near the vein, then enter the vein at a shallow angle. This will help to keep the vein taught.
- Give the patient reliable information. If you tell him that you will try only one more time before having someone else try, keep your word.
- Don't be greedy, the truism about the 18-gauge IV that runs versus the 16-gauge hematoma may be annoying when someone says it to you, but it **is** true.
- Recognize when it's "not your day" and don't be shy about having another anesthesia provider do the IV if you can't after about two (or so) tries.
- There are many individual styles of securing the IV once it is inserted, and this has

actually been the subject of scientific inquiry. One study found that the "double-chevron" method, using two pieces of tape for the hub and the barrel of the needle, gave superior results (Fig. 28.1). Flat transparent dressings are generally superior to gauze dressings. Take care not to wrap the IV tubing circumferentially around the arm or hand, and don't make "purse handles" with extra long loops of unsecured tubing.

Infrequently, but almost assuredly, you will encounter a patient in whom it seems impossible to place a peripheral IV. Difficult IV placement is more common in patients with a history of receiving IV chemotherapy, IV drug users, and the morbidly obese. If you are attempting to avoid central line placement (e.g., if the case is a quick outpatient cataract or carpal tunnel surgery), proficiency with ultrasound-guided peripheral IVs can be particularly useful. Tips for the placement of **ultrasound-guided peripheral IVs:**

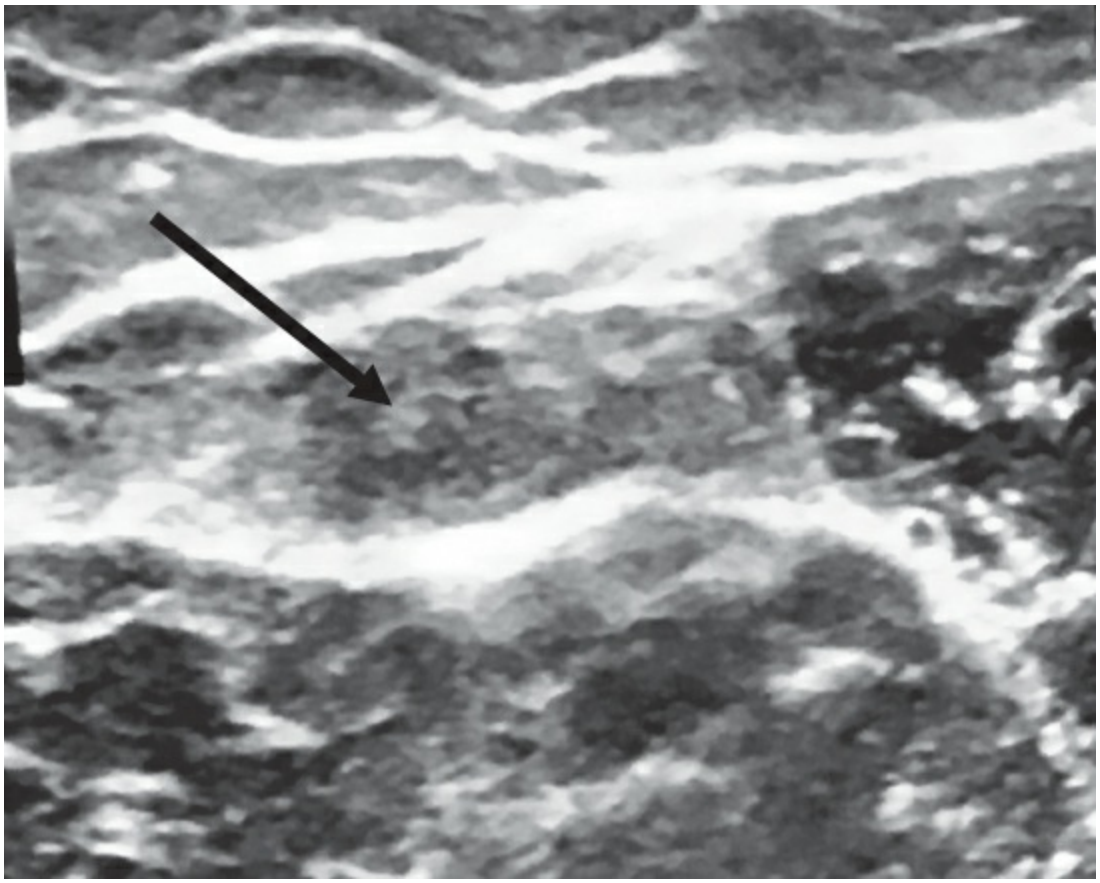

**Figure 28.2.** Image of ultrasound-guided peripheral IV placement. Note arrow pointing to tip of IV needle within the lumen of the vessel.

- Use an ultrasound transducer with a smaller profile (e.g., linear vascular 25 mm transducer [13-6 MHz] or a linear "hockey stick" transducer).
- Scan along the patient's arm to find patent vessels in the short-axis view. Vessels can usually be found in the antecubital fossa and on the inside of the upper arm (deep brachial vein). Once identified, scan to determine the general course of the vein.

- Avoid vessels that appear to have significant clot burden (appears hyperechoic and "cloudy" within the lumen).
- Determine the depth of the vein and make sure you are using an angiocatheter that is long enough to reach and thread into the vein.
- Approach the skin at a 45-degree angle. Once the lumen of the vein has been punctured and a "flash" of blood is seen within the catheter, drop your hand and decrease the angle of needle.
- Slowly advance the ultrasound probe cephalad, a millimeter at a time, while watching the tip of the needle advance within the lumen of the vessel. This will (1) prevent you from going through the opposite wall of the vein and (2) allow you to advance the needle far enough into the vein to thread the catheter (Fig. 28.2).
- The catheter should advance easily without resistance. Placement can further be confirmed by first aspirating blood from the catheter, then flushing saline into the vessel.
- Note: Because these are deeper, it is often more difficult to tell if the IV has infiltrated. Be sure that the IV flushes easily and listen to the patient if they tell you they are having pressure or pain at the site of placement.

Although a single IV is adequate for some anesthetics, sometimes it is necessary to place additional ones. This is typically done after induction, because not only does it avoid patient discomfort, the vasodilating effects of general anesthesia will often make peripheral veins more obvious. Some **indications for starting a second IV** are:

- The potential for large-volume blood loss. Although administration of medications can be done with small-caliber IVs, replacement of fluids and blood products is best done through large peripheral IVs, typically 18 gauge or larger. The larger the diameter of the catheter, the lower the resistance to flow, and the more rapidly you can push fluids. Always make sure to discuss the expected blood loss with the surgeons before the operation, and when in doubt, play it safe! Also, remember to obtain informed consent from your patient for all blood products.
- When patient positioning is such that obtaining additional IV access during surgery will be difficult. For example, if both arms will be tucked to the sides, it will be wise to start a second IV just in case one fails during the procedure.
- If you are planning to use a continuous infusion. Although it is not entirely necessary, it is sometimes preferred to use a dedicated IV at a constant rate for infusions, so that fluid and medication boluses do not disrupt the flow rate.

## TAKE HOME POINTS

- Be confident and calm when starting an IV on an awake patient.

- Remember that peripheral IV skills can atrophy a bit even during a 2-week vacation.
- Never argue with patients about their veins—if they insist they will be difficult, agree and tell them you will use the techniques used for children.
- Control the tourniquet!
- Exercise the extremity before placing the tourniquet.
- Make sure you are in the vein before trying to advance the catheter.
- Remember that the IV start is a chance to make a good impression, but unfortunately, it is also a chance to make an unfavorable impression.

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# Never Use an Intravenous Line Without Palpating and Inspecting It Visually

Mark M. Smith, MD, Ryan McHugh, MD, and Juraj Sprung, MD PhD

Unintentional intravenous (IV) infiltration and extravasation can be a source of patient injury and medical legal liability if not identified and treated appropriately. **Extravasation** is the term used to describe unintentional extravenous leakage of vesicant (an agent that causes blistering) solutions whereas **infiltration** refers to nonvesicant substances. These terms are often used interchangeably and will be termed infiltration for the purpose of this discussion except when specifically discussing vesicant solutions.

Signs of infiltration include tissue edema, skin blanching or erythema, and skin temperature change. Patients may report pain and tightness at the infiltration site. Common areas of infiltration include the hand, forearm, and antecubital fossa. Patient populations at higher risk for infiltration include critically ill and oncologic patients, owing primarily to the increased quantity of IV access sites and attempts in addition to the repeated use of cytotoxic agents. Those of extremes of age (neonates and elderly) are also higher risk for infiltration. Neonates present with small vasculature and immature skin, whereas elderly persons have fragile vasculature and often very loose subcutaneous tissue. Infiltrative injury can occur by either pressure-related or cellular irritant–related mechanisms. Before infusion of any fluid or medication, **every** IV should be carefully inspected for signs of infiltration.

## Perioperative IV Fluid Concerns

Common perioperative IV fluid therapies include crystalloid and colloid solutions. Crystalloids are water-based solutions, usually with low–molecular-weight salts (vs. ions), whereas colloids contain high–molecular-weight proteins or glucose polymers. Medication and fluids are often described as vesicants or nonvesicants. Vesicants are capable of causing direct tissue injury, and include radiocontrast dyes, certain ionic salts, vasoactive agents, and chemotherapeutic solutions. Extravasation of vesicant solutions can lead to injury by vasoconstriction, osmotic activity, pH shift, or direct

cytoxic damage. Colloid solutions may increase extravascular fluid content via osmotic forces, whereas any hypotonic solution may lead to cell rupture via intracellular fluid shifts. Dyes most often resemble hypotonic solutions and include methylene blue and indocyanine green. Infiltration with dyes may result in skin discoloration, for which resolution is dependent on the rate of dye reabsorption from the extracellular space, typically 12 to 24 hours.

## Intraoperative Monitoring

Prior to anesthetic induction, palpation of the IV access site is recommended. Fluid and/or medication administered unintentionally extravascularly may elicit pain in awake patients. Reliance on a free-flowing IV may lead to false security, particularly in the elderly for whom loose skin may allow fluid infusion despite infiltration. When using central venous catheters, positive aspiration of blood from each port must be achieved prior to injection or infusion. Multiple orifice catheters may be inadvertently withdrawn, leading to the proximal infusion port(s) no longer residing within the intended vasculature. Pressure transduction of all central access venous catheters should be performed to confirm venous as opposed to inadvertent arterial placement.

If an extremity is exposed during surgery, continuous monitoring of the IV site for edema or blanching is advised. Jewelry such as rings should be removed before surgery, especially for arms that are tucked (placed along the body and covered with drapes), and arms in which IV catheters are placed. Should IV fluid flow cease intraoperatively, full inspection of the IV site is necessary. Facilitation of sluggish IV flow by use of "pressure bags" should be avoided. If this is even considered, it should prompt the provider to examine the IV site for signs of extravasation.

## Consequences

Consequences of infiltration can be divided into pressure-related injuries and cellular irritant–related injuries. Pressure-related injuries risk tissue ischemia secondary to impaired arterial blood delivery, and/or impedance of venous drainage. Cellular irritant–related injuries result from extremes of pH, vasoconstriction, osmotic differences, and/or direct toxicity. Consequences of these injuries include: compartment syndrome, tissue necrosis, tissue ulceration, and complex regional pain syndrome. Perioperative vigilance is required when administering vesicants such as antibiotics, vasopressors, cytotoxins, and cationic and osmotically active solutions (total parenteral nutrition, hypertonic dextrose solutions, potassium, calcium, or bicarbonate salts).

## Treatment Options

Upon recognition of IV infiltration or extravasation, all infusions should be promptly discontinued, and aspiration of fluid from the catheter should be attempted. Elevate the affected extremity; providing this elevation does not interfere with extremity perfusion (pulse oximetry can be placed and used for extremity perfusion assessment). Application of warm compresses may alleviate pain and swelling in nonvesicant infiltration injuries. Cold compresses should be applied to a vesicant extravasation site for the first 24 hours, subsequent moist heat may be used but caution must be taken as this may lead to skin sloughing.

Certain vesicants have antidotes to be administered should extravasation occur. Vasopressor (phenylephrine, vasopressin, norepinephrine, epinephrine, dopamine, dobutamine, methylene blue) extravasation should be treated with intradermal injections of phentolamine (alpha-adrenergic antagonist). Hyperosmolar extravasation (total parental nutrition, calcium chloride, potassium chloride etc.) injuries are often treated with intradermal hyaluronidase injections. Many chemotherapeutic agents have specific antidotes, for which providers administering such medications should be familiar. Techniques such as tissue irrigation and liposuction have been described, but are rarely indicated. Providers must closely monitor the site of injury for induration, signs of or high probability of tissue necrosis, which if present prompt surgical consultation. Severe injuries may require invasive treatments such as fasciotomy, tissue débridement, skin grafting, or extremity amputation.

## Conclusions

IV infiltration and extravasation are rare, but potentially serious perioperative injuries. Providers must exercise vigilance when utilizing IV catheters in the perioperative settings. Should infiltration or extravasation occur, providers must be familiar with treatment strategies and antidote therapy (if warranted). Postinfiltration management should include frequent assessment of the injury site and perfusion of the affected extremity. Educating perioperative staff as to safe practice regarding intravenous access is paramount in decreasing the incidence of these complications.

### TAKE HOME POINTS

- Be familiar with patients at high risk for IV infiltration—infants and children, elderly, critically ill, and oncologic patients.
- Always visually inspect and palpate each IV prior to use—do not rely only on free-flowing fluid as a marker of intravascular catheter location.
- Do not facilitate (e.g., syringe or pressure bag) a sluggish IV—it is infiltrated until proven otherwise.

- Injuries are categorized as pressure-related or cellular irritant–related. Be familiar with hospital policies and recommended therapy for infiltration and extravasation injuries.
- Treatment ranges from conservative to invasive depending on the solution infiltrated and extent of injury.
- Call the hospital pharmacy for information regarding specific vesicant antidotes.

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30

# Intraosseous Access

Toby N. Weingarten, MD

Intraosseous (IO) needle placement has become a widely used means of rapidly obtaining access to the central venous circulation for volume resuscitation and medication administration. The IO needle is placed into the medullary cavity as an entry point into venous circulation and can be used to administer fluids, blood products, and medications as well as obtain laboratory values (type and screen, hemoglobin and basic chemistry, but not blood carbon dioxide levels or platelet count). This technique is widely endorsed for emergency clinical situations where adequate intravascular access cannot be quickly established by traditional means (peripheral or central intravenous catheter). Placement of IO needles is rapid, and thus an attractive alternative in emergency situations. Typically IO needles are used in prehospital settings for trauma/combat patients (both pediatric and adult), cardiac arrests, septic shock, and status epilepticus.

## Needle Types

Needles used for IO access require a stylet or obturator to prevent clogging with bony fragments and must be strong enough not to bend while traversing the compact bone of the cortex to the medullary cavity. A variety of IO needles are commercially available, though other needles for other uses (e.g., bone marrow biopsy needles) have been used. Commercially available IO needles can either be placed manually or with mechanical devices. Manually placed devices include Jamshidi needle (actually a bone marrow biopsy needle that can be used for IO access, manufactured by Cardinal Health, McGraw Park, IL), Sur-Fast needle, and modified Dieckmann (Cook IO) needle (both by Cook Critical Care, Bloomington, IN). These devices are notable for a handle to ease placement. Insertion is accomplished by applying pressure to the handle using a twisting motion until a loss of resistance is felt. The stylet is then removed and aspiration should produce bloody material from the marrow. A bolus of fluid should be easy flowing. Manual IO needle placement is typically used in pediatric patients because more force is needed for adult patients.

Currently, there are three mechanical device systems available for establishing IO access: the First Access for Shock Trauma system (FAST-1, FAST Responder, and FASTTactical sternal IO systems, Pyng Medical Corp, Vancouver, BC, Canada) used for sternal IO access; Big Injection Gun—BIG (WaisMed Ltd, Houston Tx) a spring-loaded delivery mechanism, or EZ-IO® Intraosseous Vascular Access System (Teleflex Incorporated, Wayne, PA) a battery-powered driver delivery mechanism. The needle sets are 15G and available in three different lengths including 15 mm (for 3 to 39 kg), 25 mm (3 kg or over), and 45 mm (40 kg or over and/or excessive tissue depth) (Fig. 30.1). Clinical judgment should be used to determine appropriate needle set selection based on patient anatomy, weight, and tissue depth. These needles have black lines on the shafts to help ensure selection of the appropriate needle length prior to entering the cortex of the bone. The needle is attached to the driver and inserted perpendicularly into selected site until the needle contacts bone. The last line (5 mm from the plastic hub) should still be visible to indicate adequate depth (if not a longer needle or different insertion site is indicated). Activate the driver with gentle downward pressure until a loss of resistance is encountered. The stylet is then removed and aspiration may produce bloody material from the marrow. **Inability to withdraw/aspirate blood from the catheter hub does not mean the insertion was unsuccessful.** Consider attempting to aspirate after the flush. Adequate flow rates are dependent on performing a rapid flush (syringe bolus) prior to IO infusion and infusing fluids and medications under pressure (e.g., infusion pressure pump or pressure bag). Gravity alone will rarely generate adequate flow rates.

**Figure 30.1.** EZ-IO® Needles. The needles are available in three different lengths including 15 mm (for 3 to 39 kg), 25 mm (3 kg or over), and 45 mm (40 kg or over and/or excessive tissue depth). (Property of Teleflex Incorporated. Copyright © 2017 Teleflex Incorporated. All rights reserved.)

## Insertion Sites

IO needles can be inserted into several locations. In conscious patients, local anesthetic should be used over the insertion site and with the priming infusion to ease discomfort, though this is not necessary for the EZ-IO system. Clean/sterile technique should be used. Needle direction should be perpendicular to the flat surface of the bone. When used in pediatric patients, some manufactures recommend angling the needle 10 to 15 degrees away from the growth plate. The proximal tibia on the flat anteromedial surface is the most common location because the cortical bone and overlying skin and tissue in that location is relatively thin. The needle is inserted in the flat aspect of the bone medial to the tibial tuberosity (in adults, 2 cm medial to the tuberosity [approximately 3 cm or 2 finger-breadths distal to the inferior aspect of the patella]) (Fig. 30.2).

The FAST devices are used to obtain IO access via the sternum at the manubrium and are widely used by military healthcare personnel. These devices are approved for adults and adolescents at least 12 years old and the only mechanical delivery system to be used for sternal IO access. These devices require manual pressure and insert a plastic catheter securely into the sternum. These devices typically require less than 1 minute for insertion and allow for rapid delivery of medications into the central circulatory system. Fluids can be infused at 250 mL/min with a syringe, but with a pressure cuff at 125 mL/min and 30 to 80 mL/min by gravity. It is recommended that these devices be used for less than 24 hours.

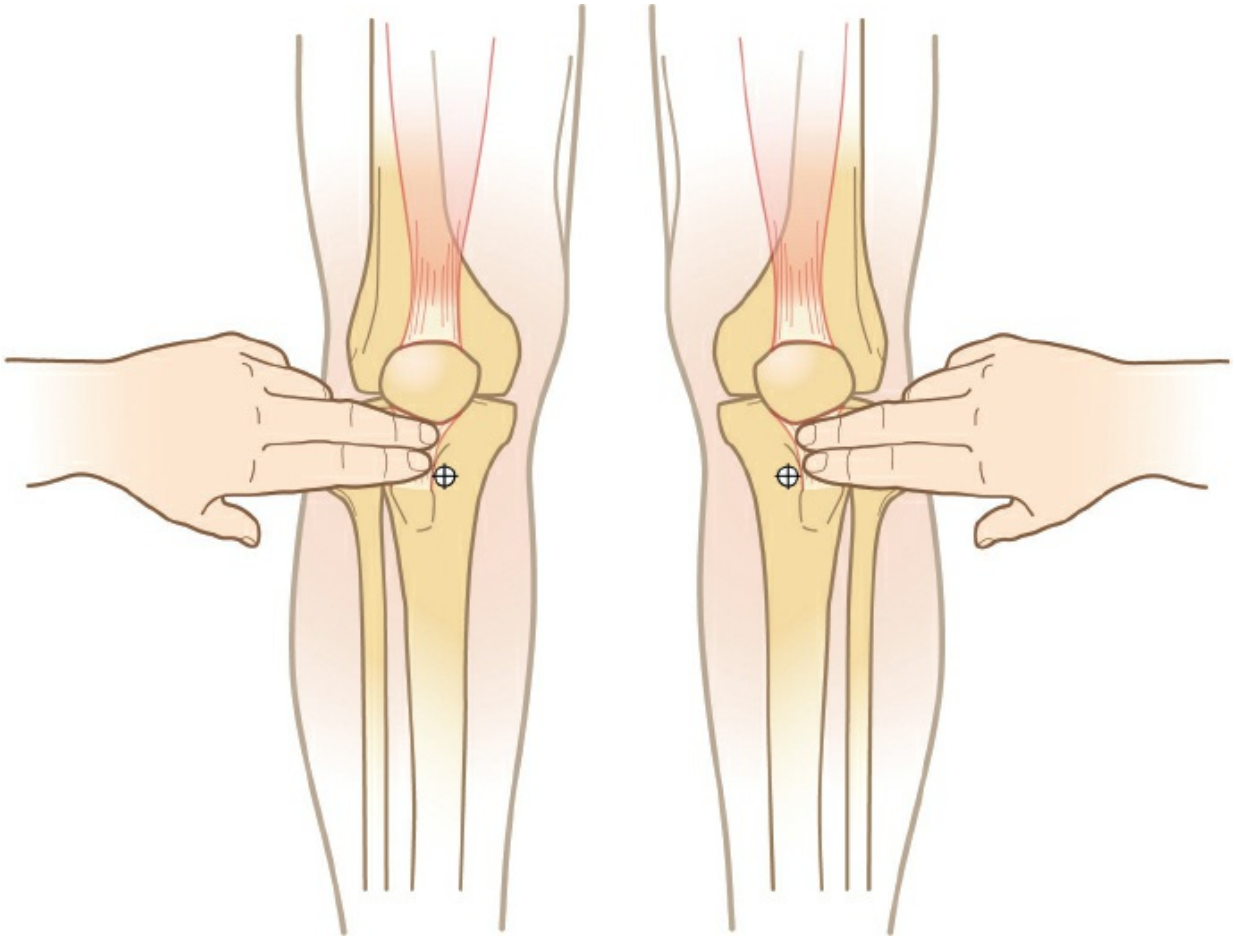

**Figure 30.2.** Proximal tibial IO insertion site. IO insertion at the proximal tibia is the flat anteromedial surface medial to the tibial tuberosity 2 cm medial to the tuberosity and 3 cm (2 finger-breadths) distal to the inferior aspect of the patella. (Property of Teleflex Incorporated. Copyright © 2017 Teleflex Incorporated. All rights reserved.)

The proximal humerus is another common location for IO needle insertion. The IO needle is placed into the greater tubercle approximately 1 cm above the surgical neck and directed at a 45-degree angle to the anterior plane to avoid the epiphyseal plate (Fig. 30.3). During needle placement the patient's hand should rest on the abdomen with

the elbow adducted. This internally rotates the humerus and protects the intertubercular groove. Once the IO needle is in place it is important to secure the arm as the IO needle can be dislodged by the acromion.

Other IO needle placement locations include the distal tibia, distal femur, radius, ulna, and ilium.

## Complications of IO Needle Placement

As with any invasive device, there is the potential for several types of complications with the use of IO needles. Insertion of IO needles should be performed with sterile technique whenever possible. However, IO needles are often placed in an uncontrolled prehospital environment, where sterile technique may not be realistic. In these circumstances, antimicrobial coverage of gram positive bacteria (e.g., Staphylococcus aureus) should be administered to decrease the likelihood of soft tissue infections or osteomyelitis. Hypertonic solutions have also been associated with the development of osteomyelitis. IO catheters should be replaced with peripheral or central venous access once clinical circumstances allow and within the United States at least within 24 hours, though some countries allow for 48 hours of use. Also to reduce the chance of infection IO needles should not be placed over infected or burnt skin or tissue.

IO needles can become dislodged during use, resulting in extravasation of infusate into the soft tissue overlying the bone. This complication has resulted in reports of compartment syndrome as well as tissue necrosis that in some cases have been so severe the affected limb required amputation. When using an IO needle it is important to frequently inspect the IO insertion site to make sure there is no swelling of the limb from the infusion of fluid or other signs that the needle has become dislodged. The FAST sternal IO system is less likely to become dislodged than other IO insertion sites. When using the proximal humerus for IO access, it is important not to move the arm because the needle can become dislodged from contact with the acromion. Extravasation can also occur if the IO needle transverses through the medullary cavity and the posterior bony cortex, so when placing an IO needle, only one loss of resistance or “pop” should be encountered. IO needles should not be placed in long bones with concomitant fractures because fluid could extravasate through the fracture site, which can interfere with bone healing or lead to a compartment syndrome. IO needles should not be inserted into a bone that had a recent previous IO needle insertion in the previous 48 hours, because fluid could extravasate from the old insertion site. Similarly, the same insertion site should not be attempted multiple times after unsuccessful IO placement, because there may be an unrecognized opening from a failed insertion that could be a route of extravasation.

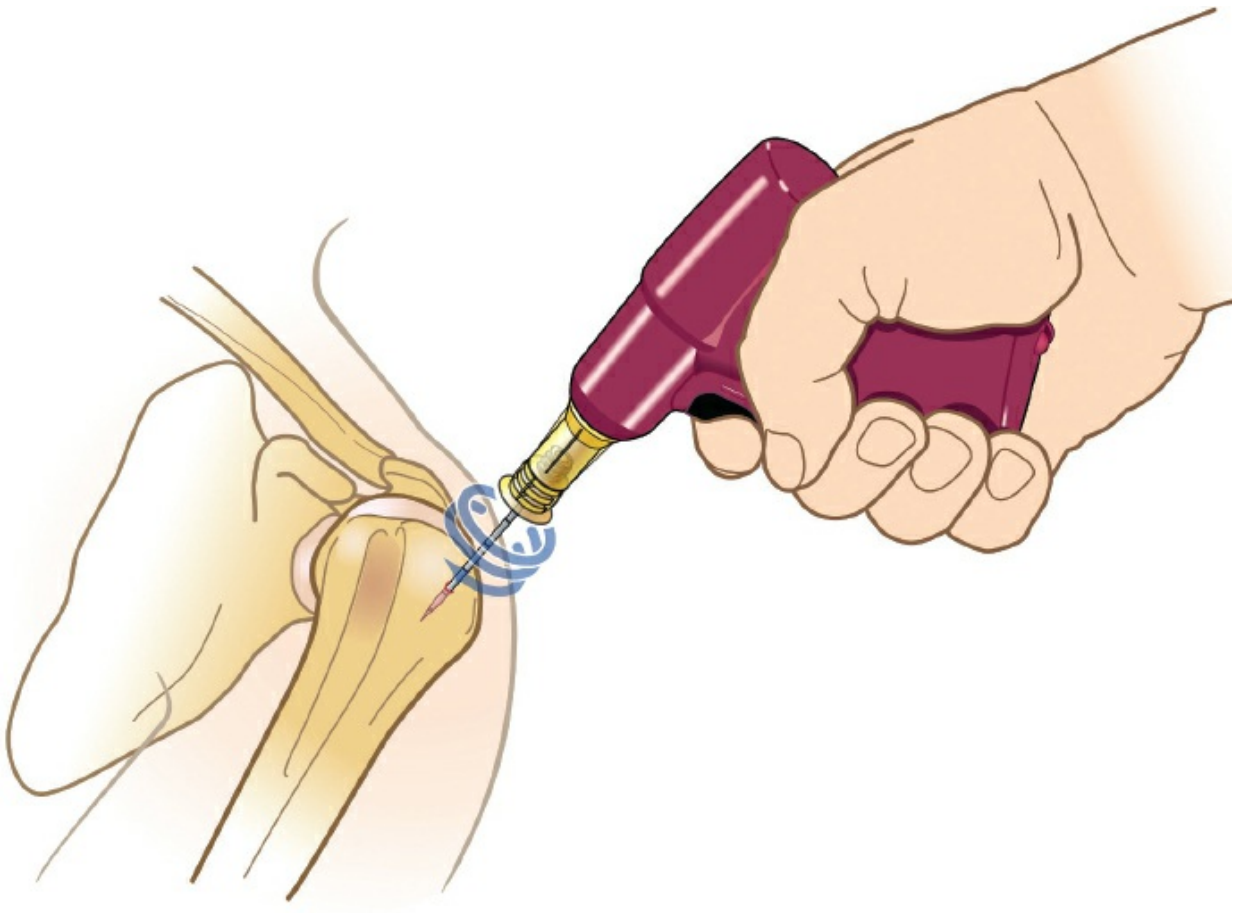

**Figure 30.3.** Proximal humerus IO insertion site. IO insertion is the greater tubercle approximately 1 cm above the surgical neck and directed at a 45-degree angle to the anterior plane to avoid the epiphyseal plate. The patient's hand should rest on the abdomen with the elbow adducted to internally rotate the humerus and protect the intertubercular groove. (Property of Teleflex Incorporated. Copyright © 2017 Teleflex Incorporated. All rights reserved.)

Another severe complication with IO placement is iatrogenic fracture. IO needles that require mechanical pressure for placement should not be placed in patients with pathologic bony conditions such as osteogenesis imperfecta or severe osteoporosis. Excessive force should not be used to place IO needles to avoid trauma. The delivery system used for EZ-IO needle placement requires minimal force for insertion with less disruption of the bony architecture and may be an option for patients with underlying bone weakness.

Other complications result from failure to successfully insert the IO needle. The correct needle length should be selected for the patient's size. Up to 10% of practitioners can still have difficulty penetrating the periosteum with manual IO needle placement. IO needles can bend or break during insertion. Patients can complain of pain with insertion of IO needles, and when not in extremis efforts should be taken to provide analgesia over the insertion site. Other complications include catheter bending or clogging, dermal abrasions, and difficulty removing the IO device.

## TAKE HOME POINTS

- IO Needles can be used to rapidly gain access to the central vascular system in emergent settings when traditional intravenous access is not feasible.
- IO access can be used to infuse intravenous fluid, blood products, and medications.
- IO needles are most commonly placed in the proximal tibia, proximal humerus, and sternum.
- IO needles are rarely complicated by infections, but placement using sterile technique and leaving in place only until an alternate means of intravascular access can be secured will help prevent this rare complication.
- Extravasation of fluid is another serious complication and has led to compartment syndrome and tissue necrosis. The IO insertion site should be inspected frequently to ensure that extravasation does not occur.
- IO needles should not be placed into a bone with an unhealed fracture.
- Caution should be used with IO needle placement in patients with bone pathology that can weaken the bone such as osteogenesis imperfecta.

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31

# Central Line Placement: Never Neglect the Basics

Hassan Mohamed, MD and Brian T. Gierl, MD

Intravenous (IV) access is a crucial part of anesthesia care, and placement and management of lines are important skills for both the anesthetist and anesthesiologist. Virtually all anesthetics require some degree of IV access, whether it is for induction of general anesthesia, administration of medications, fluid resuscitation, or blood sampling.

Before attempting to place a central line, be sure you are well versed on anatomic landmarks and appropriate techniques. This is never a benign procedure, so always make sure to weigh the risks and benefits and discuss them with the patient as part of your informed consent process. Central line placement has been associated with several complications, including:

- Accidental arterial puncture with pseudoaneurysm or hematoma
- Pneumo- or hemothorax
- Venous air embolism (VAE)
- Infection and sepsis
- Cardiac arrhythmias

The decision to place a central line is multifactorial. Always assess the overall clinical picture, and discuss with the surgeon and intensive care unit (ICU) staff if possible. Some of the indications for obtaining central venous access are:

- Inability to obtain peripheral venous access.
- Cardiac arrest or “code” situation. In this case, a femoral approach is best, as it does not interfere with chest compressions or endotracheal intubation.
- Administration of certain medications. Generally, any medication that can cause direct damage to peripheral veins must be given centrally, for example, 3% saline. Also, highly concentrated vasopressors can cause vasospasm if given through a peripheral vein. Check with the pharmacy for other medications that need to be given centrally.
- Central venous pressure monitoring. Although not considered to be a highly accurate measure of volume status, it can be used in conjunction with other clinical signs to

guide fluid management.

- Massive blood transfusion. As mentioned above, large-diameter catheters are preferred for rapid transfusion, but remember that the **length** of the catheter also contributes to resistance to flow. For example, a short 16-gauge peripheral IV has much less resistance than a long 16-gauge central line. For rapid infusion of large volumes, a large-bore, short catheter, such as a Cordis or introducer sheath, is best.
- Potential need for a pulmonary artery catheter placement. A right-sided internal jugular or left-sided subclavian introducer is preferred.
- High risk of VAE during surgery. Be familiar with the clinical signs of VAE and potentially high-risk procedures. In addition to placement in the left-lateral decubitus position, flooding the surgical field with fluid, increasing $FiO_2$, and discontinuing nitrous oxide, aspirating through a central line may remove air from the right side of the heart. In this case, a multilumen catheter is preferred.

Some basic things **always** to remember when placing a central line:

- Be aware of coagulopathy, thrombocytopenia, or any other contraindication to a particular line (thrombosis, existing hardware, etc).
- Choose your site wisely. For example, in a patient with a right-sided pneumothorax, choose a right IJ or SC to avoid the risk of bilateral pneumothoraces.
- Place your patient in Trendelenburg position, or at least flat, when placing an internal jugular or subclavian line. This minimizes the risk of VAE.
- Create a sterile field. Studies have shown that infection risk decreases significantly when proper sterile techniques, including a full-body drape, are used.
- Be familiar with your supplies and have them ready and within your reach before you begin the procedure. Get an experienced nurse to help you whenever possible.
- Be aware of your patient's condition during the procedure. Draping can make an awake patient very anxious, and a head-down position can exacerbate orthopnea or gastric reflux. Use monitoring and inhaled oxygen whenever possible.
- Always have control of the guidewire!
- Confirm venous (versus arterial) placement. There are several ways to do this. The most accurate is ultrasound-guided placement. However, if you do not have access to that equipment and the clinical situation warrants central line placement, the options include a simple "drop-test," transducing a pressure tracing, or obtaining a radiograph. Do not use the line until you are convinced it is in the right place.
- Secure the line with sutures and a sterile dressing.

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32

# Avoid Technique-Related Central Venous Catheter Complications by Using Modern Tools

J. Saxon Gilbert, MD and Karen Hand, MB BS FRCA

Placement of central venous catheters is a routine procedure in modern anesthesia care. The somewhat routine nature of this procedure should not lull the anesthesia provider into complacency regarding the importance of meticulous attention to technique. Of the many thousands of central venous catheters placed each year, the U.S. Food and Drug Administration (FDA) estimates that approximately 10% will be associated with a complication, 52% of which are related to practitioner technique. The cost of these complications to the U.S. health care system exceeds ∃1 billion annually.

In anesthesia practice, right internal jugular vein cannulation is most commonly selected. This is because of the relatively straight path to the superior vena cava, increased distance from the cupola of the lung (vs. left side), and absence of the thoracic duct on the right side. The potential for nerve, vessel, or lung injury exists for any approach to central venous catheterization, including the right internal jugular approach. The subclavian approach increases the risk of pneumothorax because of the proximity of the pleura to the subclavian vein. In addition, if the subclavian artery is punctured, it is not possible to control hemorrhage with direct pressure. Femoral vein cannulation is associated with increased risk of infection, but can be a good alternative if the line is intended for rapid volume infusion. Peripherally inserted central catheters can also be used. Catheter length hinders this option for the purpose of rapid volume infusion.

Although infections are responsible for approximately 75% of catheter complications, American Society of Anesthesiologists (ASA) closed claims data indicate that technical complications during placement are the most deadly. Pneumothorax, wire or catheter embolization, air embolism, extravasation of fluid or blood into the neck, and a variety of cardiac and vascular injuries may occur. Of these, direct arterial injury and vascular injury resulting in cardiac tamponade or hemo/hydrothorax have the worst mortality (Table 32.1).

In addition to site of catheter placement, the risk of pneumothorax can be diminished

by using ultrasonic guidance and properly angling the needle away from the pleura on initial approach to the vessel.

- Wire embolization is avoided by using a technique of catheter insertion that permits one hand to continuously control the wire until it is removed.

**Table 32.1 ■ Overall Complications and Fatalities for the Periods 1978–1989 and 1990 and Later**

| Complications | 1978–1989 | 1978–1989 Fatalities | 1990 and Later | 1990 and Later Fatalities |
|---|---|---|---|---|
| Cardiac tamponade | 10 | 8 | 2 | 2 |
| Wire or catheter embolism | 10 | 0 | 0 | 0 |
| Vascular injuries | 16 | 9 | 16 | 7 |
| Hemothorax | 6 | 6 | 5 | 3 |
| Hydrothorax | 3 | 1 | 1 | 1 |
| Carotid artery injury | 5 | 1 | 9 | 3 |
| Subclavian artery injury | 2 | 1 | 1 | 0 |
| Pulmonary artery rupture | 4 | 4 | 1 | 1 |
| Pneumothorax | 7 | 1 | 3 | 0 |
| Air embolism | 2 | 1 | 1 | 1 |
| Fluid extravasation in neck | 0 | 0 | 3 | 1 |
| Total | 49 | 23 | 26 | 12 |

- Catheter embolization is prevented by taking care to avoid withdrawing the catheter at any time over a needle with a cutting bevel, which can shear the tip. Air embolization is of particular concern when the patient is breathing spontaneously or when the insertion site is above the level of the heart. Avoid this complication by using the Trendelenburg position (which improves identification of neck vessels as well), occluding the catheter/introducer with a gloved finger, and taking care to eliminate air from the catheter itself with aspiration and flushing either before or after insertion.
- The risk of fluid or blood extravasation is avoided by ensuring that the skin nick for the introducer does not lacerate the vein being cannulated, and by suturing the catheter securely to avoid the tip slipping.
- Cardiac tamponade usually results from a catheter with the tip inside the right atrium or angled against the wall of the superior vena cava, which can erode through the thin-walled atrium or vessel. This usually occurs after hours or days.
- The most serious direct vascular injury is caused by the inadvertent insertion of the

catheter or introducer sheath directly into an artery that was mistaken for a vein.

Eliminating life-threatening vascular complications entails correct positioning of the introducer and catheter within the appropriate central vein. Fortunately, modern tools are available to assist the anesthesia provider in correct placement and definitive confirmation that the catheter will be inserted into a vein and not an artery. Subjective methods of ascertaining correct placement such as evaluation of the pulsatile quality or color of the blood are unreliable. This is because they can depend on variable factors such as oxygen saturation of the blood or arterial/venous pressure. Use of two-dimensional ultrasound as a guide to initial venous puncture is the best means of avoiding insertion complications. A 2001 review of the literature by the Agency for Healthcare Research and Quality revealed that use of ultrasound for placement of central venous catheters improved catheter insertion success rate, diminished the number of venipuncture attempts, and reduced the number of overall line complications.

The best means of confirming correct line placement is a two-step process: step one is to transduce the pressure in the vessel before placing the introducer (ensure that it is not an arterial waveform), and step two is to confirm proper placement via a chest radiograph either intraoperatively or at the end of the procedure. A retrospective study of 1,021 central lines by Jobes et al. revealed that among 43 cases of arterial puncture, five resulted in inadvertent placement of 8.5-French catheters in the carotid artery and one patient subsequently died. Conversely, in a prospective study of 1,284 central line placements in which the line was transduced after insertion, unrecognized arterial puncture was detected in 10 patients and there were no inadvertent arterial cannulations.

## TAKE HOME POINTS

- Beside infections, the majority of central venous catheter complications are secondary to technical problems.
- Minimizing serious complications related to central venous catheter insertion can be accomplished by using the techniques discussed above. Review them periodically and mentally visualize and rehearse affording them!
- Strict aseptic technique and avoiding confusion between artery and vein are paramount.
- Using modern tools such as two-dimensional ultrasound and pressure transducers has been shown to reduce the number of life-threatening complications.
- Keep in mind the primary dictum of medical practice when inserting central lines: First, do no harm!

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33

# Pulmonary Artery Catheters—Still Relevant and Still Worthy of a Cautious Approach

Valerie Sera, DDS MD, Jarna R. Shah, MD, Matthew W. Caldwell, MD, and Erica D. Wittwer, MD PhD

> "I can understand perfectly how the report of my illness got about, I have even heard on good authority that I was dead. James Ross Clemens, a cousin of mine, was seriously ill two or three weeks ago in London, but is well now. The report of my illness grew out of his illness. **The report of my death was an exaggeration**."
>
> –Mark Twain

We had quite a lively discussion, while updating this chapter for the second edition, on the relevance and use of the pulmonary artery catheter (PAC) in today's practice of anesthesiology. The debate was precipitated by a retrospective observational study by Xu et al. that reported on 1,360 Chinese patients undergoing primary coronary artery bypass grafting. This study noted that PAC placement was linked with increased perioperative cost. The authors further concluded that, "There is no clear indication of any benefit or harm in managing CABG patients with PAC. However, use of PAC in CABG is more expensive. That is, PAC use increased costs without benefit and thus appears unjustified for routine use in CABG surgery."

The very experienced clinicians who have revised and edited this edition are not entirely in agreement, to put it mildly. For example, the Mayo Clinic and the Oregon Health and Science University use them in the cardiac surgery rooms on almost all patients. Of course, Status 1A patients waiting for heart transplant must have a PAC, often for quite a considerable interval. Transesophageal echocardiography (TEE) is also routinely used intraoperatively, but the PAC is still found to be very helpful both in the operating room and in the postoperative titration of inotropes and vasopressors in these patients. The PAC is also used in the ICUs for patients with pulmonary hypertension and right ventricular dysfunction, that is, it is a critical tool for perioperative care of the failing heart. There was a facetious comment in our discussion that sometimes perioperative clinicians who pooh-pooh their use the most are the first to call for a PAC when their septic patients with bad hearts don't get better with fluids.

Similarly, our friends in Ohio also still use them in many (but not all) cardiac surgery cases and find that their use is somewhat surgeon-dependent. This is supported by a recent study by the Society of Cardiovascular Anesthesiologists (SCA) that surveyed SCA members in North America, Europe, Asia, Australia, New Zealand, and South America. The respondents preferred to use the PA catheter for most cardiac surgeries, in conjunction with TEE as the most popular complimentary hemodynamic monitor. This study also reported that, "Subgroup analysis of the data revealed that geographical location, type of practice, and surgeons support played a significant role in the decision to use a PAC."

So, with the continued widespread use of PACs, let's once again review the fundamentals.

Fegler introduced the thermodilution method for measuring blood flow in 1954. The introduction of the flow-directed PAC in the 1970s permitted clinicians to measure intracardiac pressures directly. Hemodynamic data gathered from PAC use are widely used to diagnose and help guide medical therapy in critically ill patients in the operating room, cardiac catheterization laboratory, and intensive care unit. As we stated above, such data can be helpful in differentiating between cardiogenic and noncardiogenic shock and in guiding decision making about fluid, vasoactive, and inotropic drug therapy over time. For the patient to benefit from PAC use, the clinician must thoroughly understand the interpretation and use of hemodynamic data and must be well aware of the limitations of data obtained from PAC use. Although pulmonary artery catheterization has not been proven to improve outcome, expert opinion continues to support its judicious use after evaluation of the potential risks and benefits for each patient (Pulmonary Artery Catheter Consensus Conference 1997).

## How PAC Technology Works

The PAC is 100 cm long, with proximal and distal ports that enable the measurement of intravascular and intracardiac pressures and the sampling of blood as well as the infusion of vasoactive and inotropic drugs and fluids. At the very tip of the PAC lies the thermistor. The thermistor, when appropriately positioned in the pulmonary artery, continuously measures the temperature of the blood passing by the tip of the PAC in the pulmonary artery. Relatively cold (iced or room-temperature) fluid is injected into the right atrium via the proximal port of the PAC and decreases the temperature of the blood passing distally by the thermistor into the pulmonary circulation. A thermodilution curve is generated by plotting the decline in the pulmonary artery temperature against time in seconds. The area under the curve is integrated and then incorporated into the Stewart-Hamilton equation to yield the cardiac output (CO):

$$CO = [V \times (T_b - T_i) \times K_1 \times K_2] / [\int \Delta T_b(t)\, dt]$$

where V, volume of injectate; $T_b$, temperature of blood; $T_i$, temperature of injectate; $K_1$, density factor; $K_2$, computation constant; and $\int \Delta T_b(t)dt$, integral of blood temperature over time. The computation constant is specific to the brand of catheter and it incorporates specific variations in the catheter dead space, approximate injection temperature, injection rate, heat exchange, and unit conversion. The greater the CO, the smaller the temperature change over time. Matching the constant with the correct volume (5 or 10 cc) and temperature (iced or room-temperature) of injectate to be used is imperative. Dissection of this equation exposes a number of data points that, if inaccurately obtained, will result in a miscalculated CO, which may lead to an inaccurate diagnosis and a misguided therapy.

## Placement and Risk

Assessing the overall risks and benefits of placing a PAC is important. Placing a PAC not only permits calculation of CO but also permits direct measurement of pulmonary-artery systolic, diastolic, and mean pressures and right heart filling pressures as well as indirect measurement of left ventricular filling pressures. Figure 33.1 depicts the correct path of the PAC through the right heart. An extra port in the PAC permits direct infusion of vasoactive and inotropic drugs into the central venous circulation.

Placing the large-bore catheter that allows the introduction of the PAC into the central venous circulation poses risks for infection, pneumothorax, hemothorax, and bleeding at the puncture site or from disconnection of a line. One of the most common risks in placing a PAC is the development of arrhythmias while the PAC floats through the right atrium and ventricle to the pulmonary artery. These arrhythmias can range from a few beats with no hemodynamic sequelae to a persistent arrhythmia that may drop the blood pressure precipitously. In the event of a significant arrhythmia, the balloon should be let down and the PAC pulled back immediately. While less common, complete heart block can occur in patients with a pre-existing left bundle branch block (LBBB). This may result in a hemodynamic emergency. The decision to place a PAC in a patient with a LBBB must weigh the risks and benefits carefully. In patients undergoing cardiac surgery, one option is to wait to float the PAC catheter until after the sternotomy has been performed and the surgeon has access to the heart. Another significant complication may occur in cardiac surgical procedures, which is the PAC may be entrapped by suture unintentionally. This can occur during valve placement or during closure of the right atrium after venous decannulation. It is imperative to check the PAC for the ability to mobilize freely following a cardiac surgical procedure. The most devastating complication associated with PAC use is pulmonary artery rupture.

Although pulmonary artery rupture with hemorrhage is infrequent, with an incidence of 0.2%, it is associated with a mortality rate of up to 50%. The right pulmonary artery is involved in 93% of such cases, which usually affects the right lower or middle lobe branches.

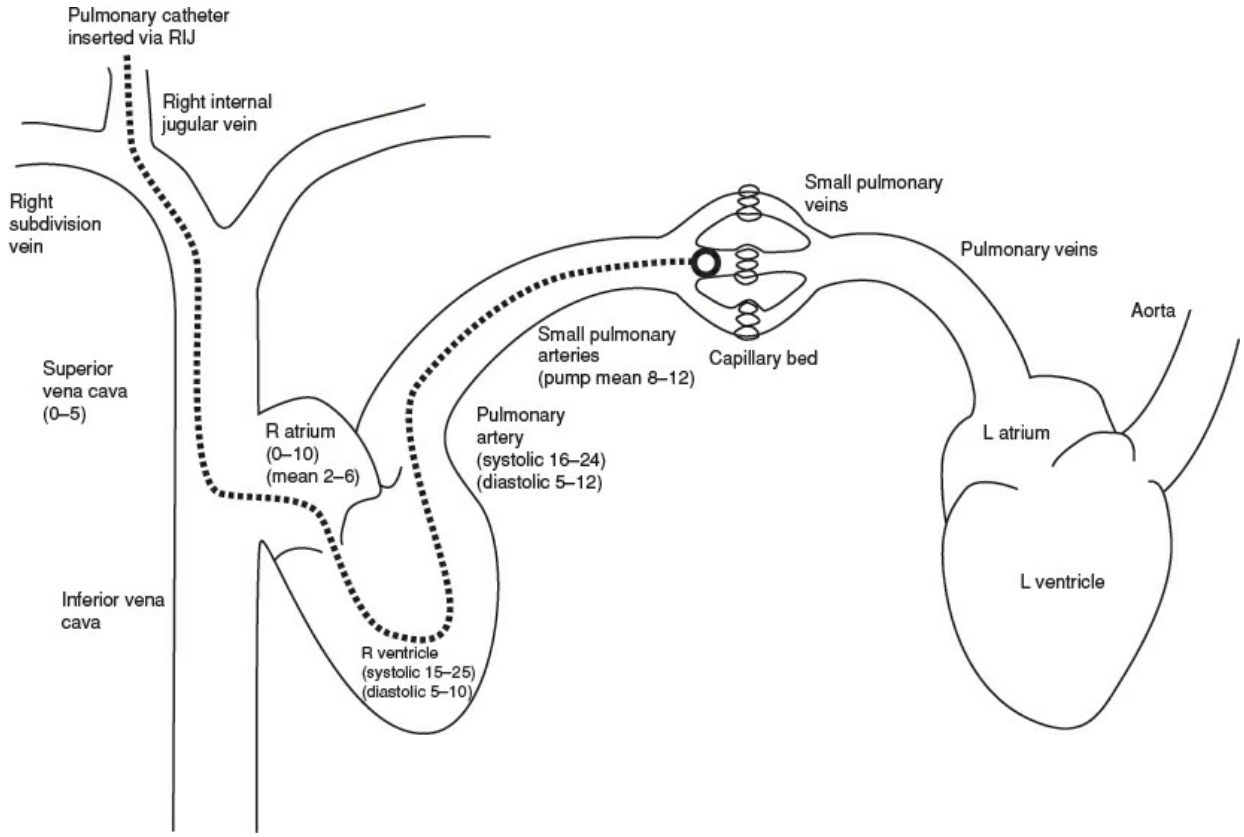


**Figure 33.1.** The path of a PAC through the right heart chambers to the pulmonary artery and the relation of PCWP to left atrium pressure. Normal pressures are given in mmHg. RIJ, right internal jugular vein.

## Errors of Management

Keep in mind that the thermodilution method measures pulmonary blood flow. Under normal circumstances, pulmonary blood flow equals systemic blood flow. The presence of intracardiac shunts, tricuspid regurgitation (TR), and cardiac arrhythmias, and rapid infusion of intravascular fluid can affect the accuracy of thermodilution CO measurements. The presence of a left-to-right shunt will yield a falsely high CO, because the pulmonary blood flow exceeds the systemic blood flow by an amount equal to the left-to-right shunt. The presence of significant TR makes the CO calculations unreliable. It invalidates the thermodilution method, because a portion of the cold indicator continues to stay in the right atrium and right ventricle, therefore not producing a significant change in blood temperature. The presence of cardiac dysrhythmias alters the beat-to-beat cardiac ejection, thereby yielding an inaccurate CO.

The accuracy of the CO calculation depends highly on operator consistency. Averaging at least three measurements made by the same operator yields the most reliable results, eliminating interoperator inconsistency and improving the precision of the CO calculation. The number of measurements averaged for each determination greatly affects the standard error of the mean (SEM), which is the basis for predicting reproducibility. There is a 2% to 5% variance in SEM when three measurements are averaged to calculate a single CO, and there is a 3% to 9% variance in SEM when only one measurement is used. When comparing CO over time and using three measurements per CO determination, a difference of 15% or more is needed to indicate that the results are actually different. If only one measurement per CO determination is used, then a difference of 26% or more is needed to indicate that the results are actually different. Therefore, at least three measurements should be done by the same operator and the average should be used to calculate CO.

Five or 10 mL of room-temperature or colder injectate should be selected, both of which have been shown to produce accurate and reproducible results. The volume and temperature must remain consistent. Variations in the injectate volume alter results. Excess volume yields falsely low CO calculations, whereas inadequate volume yields falsely high CO calculations. Injectate should be administered steadily over 2 to 4 seconds. Deviation from this rate may alter heat transfer with the surrounding tissues, reducing the accuracy of the computation constant. A faster rate of injection may affect filling volume for the cardiac cycles being measured. Measurements used to calculate CO should be done at end expiration because there is less variability in the baseline pulmonary artery blood temperature at that time.

## Errors of Interpretation

Whether the risk-to-benefit ratio favors use of the PAC in critically ill patients remains "in discussion" in the critical care community, as noted above. However, it remains one of the procedures most commonly done on critically ill patients around the world. For more than three decades, the PAC has been used primarily to monitor cardiac function via the thermodilution method, and it is also used to indicate left-ventricular end-diastolic pressure (LVEDP) and left-ventricular end-diastolic volume (LVEDV) status by measuring the pulmonary artery occlusion pressure (PAOP). Measuring PAOP and thereby indicating LVEDP in a critically ill patient permits more accurate prediction of the change in CO in response to a fluid challenge. To use PAOP as an accurate surrogate for LVEDP or LVEDV, the PAOP tracing must be valid, accurate, and correctly interpreted. The PAOP must reflect LVEDP accurately; and most importantly, the relation between LVEDP and LVEDV must be predictable.

Normally the relation between LVEDP and LVEDV depends on ventricular

compliance and when graphed, has a characteristic curvilinear appearance. The criteria noted in the previous paragraph for the use of PAOP as an accurate surrogate for LVEDP or LVEDV are not likely to be met simultaneously in a clinical setting. In addition, the presence of other clinical factors, such as mechanical ventilation or positive end-expiratory pressure, may reduce the accuracy. The change in PAOP after a fluid challenge appears to indicate better left-ventricular compliance than it does left-ventricular filling. However, the change in CO may indicate the position of the left ventricle on the Frank–Starling curve. Many studies have shown that PAOP does not indicate LVEDP reliably and predicts recruitable CO poorly.

## Alternative or Supplemental Techniques

While assessing patients using data derived from the PAC remains the gold standard, with advances in technology, other modalities have become available to the clinician. In critically ill patients, clinician assessment of left-ventricular dysfunction and ventricular preload status showed lower predictive probability than assessment by TEE. Unfortunately, extensive training in and experience with TEE are necessary for its use in assessing ventricular function, volume status, and CO, and such training and experience are not universal among intensive care unit and operating room personnel. In addition, TEE probe placement also carries the risk including trauma and esophageal perforation. Physicians have been shown to acquire skill rapidly in using transthoracic echocardiography (TTE) to assess volume only. Potential use of TTE to estimate LVEDV directly, using CO, is quite promising.

There are additional ways to measure CO and they have limitations of their own. Esophageal Doppler has been used to guide fluid therapy by optimizing stroke volume in cases in which the patient has lost a large amount of blood, and its use has been shown to reduce the length of hospital stay. By integrating the velocity of blood flow through the aorta over time and multiplying it by the cross-sectional area of the aorta, a stroke volume is determined, conferring information on contractility, preload, and vascular resistance. This method has technical limitations. Frequent adjustment of the Doppler probe is necessary for accurate measurements, and calculation of stroke volume depends on the cross-sectional area of the aorta being cylindrical and not changing over time. The Doppler method's advantage is that it is much less invasive than other methods; however, the learning curve associated with its use is steep. Its use is limited to intubated patients.

Pulse contour analysis assumes that the elasticity and impedance of the aorta remain constant and that the shape of arterial pulsation is proportional to the stroke volume. To determine the elasticity and impedance of the aorta, an independent CO determination by indicator dilution must be made. Some systems for doing so exist, have been

validated, and are slowly emerging in the marketplace. The most reliable systems tend to be the most invasive. For example, one reliable system requires the use of a central line and a femoral arterial line for optimal calibration. A review of five-pulse contour analysis systems were compared with thermodilution and in hemodynamically stable conditions good accuracy was found. However, when hemodynamic conditions were unstable the error was quite high (45%). In stable patients with heart failure, pulse contour analysis has been shown to overestimate the CO. Similarly, in patients with mechanical support such as a left ventricular assist device, pulse contour analysis will not be useful. Thoracic bioimpedance, carbon dioxide rebreathing, and perfusion surrogates are other methods, but are clumsy and clinically impractical.

**Table 33.1 ■ Certain Variables' Effect on the Cardiac Output**

| Technical Errors | Measurement Error Consequence | Comment |
|---|---|---|
| Rate of injection too slow >4 sec | Inaccurate CO | |
| Rate of injection too fast <2 sec | Inaccurate CO | |
| Falsely high computation constant | Falsely high CO | May occur if entered constant for room-temperature injection when using iced injection |
| Falsely low computation constant | Falsely low CO | May occur if entered constant for iced injection when using room-temperature injection |
| Excess volume injected | Falsely low CO | Will cause larger temperature change at catheter tip |
| Inadequate volume injected | Falsely high CO | Will cause smaller temperature change at catheter tip |
| L → R shunt | Falsely elevated CO | Pulmonary CO > systemic CO |

| | | |
|---|---|---|
| Tricuspid regurgitation | Falsely elevated CO | |
| Cardiac dysrhythmias | Less precise result | Greater beat-to-beat variability |

Table 33.1 illustrates certain variables' effects on CO accuracy.

## TAKE HOME POINTS

- The risks of inserting a PAC should be weighed carefully against the value of the data that will be obtained.
- Operator knowledge and experience influence the reliability of CO measurements.
- Taking at least three measurements and using the average is important because of the variability among measurements.
- Inputting the correct catheter constant is essential to obtaining a valid CO measurement.
- Operator consistency increases the accuracy of the CO measurement.
- Understanding the limitations of PAOP as a surrogate of LVEDV is important.
- Using TEE or TTE along with CO may provide the most complete picture of a patient's cardiovascular status.

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# Don’t Overflush Lines

Julie Marshall, MD and Peter Rock, MD MBA FCCM

Anesthesiologists become experts at the placement of intravascular catheters for access and monitoring, but they are less familiar with the routine care and maintenance of these devices. One such issue is how to balance the need to flush an intravascular catheter so that it does not clot against the necessity to avoid flushing with an excess amount of fluid that can potentially harm the patient. Unintentional overflushing of arterial and central lines happens commonly (especially during the busier intervals in a procedure) and can lead to significant complications. Also, patients not infrequently come to the operating room (OR) or intensive care unit (ICU) with indwelling devices already in place. These may be accessed for use in the OR, provided that the anesthesia providers have a plan and proceed carefully.

Let’s talk about arterial catheters, first. Overzealous flushing of arterial catheters may lead to retrograde embolization of air or clot into the central arterial circulation. It has been shown that the saline volume needed to reach the junction of the subclavian and vertebral arteries from a radial artery catheter averages just 6.6 mL. Arterial catheter continuous flush devices deliver 3 mL/hr of saline, sometimes with heparin, at a pressure of 300 mmHg. An exuberant flush of the catheter using the flush valve or with a syringe increases the volume and rate of delivery of the fluid used to keep the catheter clear of blood. Reports have shown that an increased rate of delivery, smaller patient size (infants), and increased flush volume all increase the potential for embolization of air bubbles into the central arterial circulation. To decrease the risk of embolization, all air should be removed from the arterial line. The drip chamber in the flush bag should be completely filled with fluid to decrease the chance of entraining air. Volume and rate of flush should be limited by opening the flush valve for short periods of time. When flushing an arterial catheter with a syringe, care should be taken to limit the flow rate to less than 1 mL/sec. Both the injection port and the syringe should be free of air.

Embolization of clots from stopcocks, connecting the tubing from within the arterial line or attached to the end of the catheter can also occur. If the catheter is not cleared following its use to obtain a blood sample, small clots may form in the arterial catheter itself, the connecting tubing, or stopcocks. These small clots can then be embolized with

a forceful flush. These emboli have the possibility of entering the central circulation or embolizing peripherally to cause tissue ischemia. Care should be taken to monitor for clots in the catheter and avoid forceful flushing.

Now let's move on to talk about venous catheters. Central venous catheters and vascular access devices for dialysis are common in the OR and ICU population. Lumens not connected to continuous infusions require intermittent flushing to remain patent or before being put into use. Every catheter that remains patent is one less device that will need to be replaced. As with arterial catheters, there is risk of air and clot embolization with excessive flushing of lines or lack of vigilance in eliminating air and clot from circuits and injections. Infection from indwelling catheters is a serious and frequent occurrence. Using good aseptic technique (i.e., using alcohol or chlorhexidine to clean the access port before flushing or accessing lines) will help decrease this risk. **Before flushing, the line should be aspirated and the old blood that has been contained within the catheter should be discarded**. There are several reasons to do this. First, as already mentioned, there is no reason to flush into the circulation clots that may have formed as a result of stagnant blood in the catheter. In addition, blood is a good culture medium and it is possible that this stagnant blood may be colonized with bacteria. Lastly, indwelling catheters such as the Groshong, Broviac, and PICC lines may have heparin in their lumens. It is good general practice to not flush heparin solution into the patient. Most central venous catheters list the volume of the dead space of the catheter tubing on the packaging or on the lumen of the catheter. Typically, it is this volume that would be filled with heparin flush, and it would be this volume that should be aspirated and discarded.

Patients may come to the OR with special vascular access devices (intended for long-term fluid and medication administration or nutritional support) that are surgically implanted and tunnelled under the skin. Some examples are Port-A-Caths, Q-Ports, and Infuse-A-Ports. These can be useful devices for anesthesiologists in patients with poor venous access. However, there are also several caveats to accessing these ports. It is important to ascertain the following information:

- The indication for placement of the central venous catheter
- How the catheter has been maintained
- When it was last accessed
- Whether the catheter is being used for ongoing chemotherapy treatments
- Whether any of the ports have been reserved for delivery of parenteral nutrition and therefore should be avoided; and
- How to access the device

Maintaining the aseptic technique is imperative, including using sterile gloves and cleaning the port site with chlorhexidine. Palpate the skin to find the port septum, which

may be on the top or the side of the device. To avoid damage to the septum, a noncoring needle (usually a right-angle Huber needle) is used to access the port. The needle is pushed through the septum until it hits the bottom of the reservoir. Aspirate for blood, discard the old blood, flush with saline, and then apply a sterile dressing. The needle can be connected to an infusion or an extension set and flushed per institution practice. Before deaccessing, the port is flushed with a heparinized solution (minimum volume to fill the lumen and reservoir) to maintain patency.

It is important to use the appropriate amount of heparin, as an excessive amount may lead to unintentional systemic anticoagulation. If there is uncertainty regarding whether the port can or should be used and how to deaccess it, contact the service that placed or is directing its use. Usually, the oncology or chemotherapy staff will be able to advise you. Remember that these needles and ports are designed for slow drips, not for boluses, because chemotherapy is generally given over several hours. They will not look or infuse the way a normal "induction IV" does and caution must be taken when using them to induce anesthesia in a patient.

Indwelling catheters for access and hemodynamic monitoring are necessary and useful devices in anesthesiology. However, these lines have the potential for complications. Knowing the proper methods of care and access will decrease these risks and improve perioperative patient care.

## TAKE HOME POINTS

- The volume of the arterial tree from the radial artery to the vertebral artery averages only 6 mL!
- Never "power flush" the arterial line either by hand at a rate greater than 1 mL/sec or via a prolonged flush through the valve.
- Don't flush a line if there are visible air bubbles or clots in either the central or arterial line.
- Remember that there is a significant amount of heparin in the lumens of the common indwelling catheters—always withdraw from them before you flush.
- Vascular access ports must be accessed with a noncoring needle to avoid damaging the diaphragm of the reservoir.

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35

# Inadvertent Intra-Arterial Injection Can Result in Severe Patient Injury

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The estimated incidence of iatrogenic complication from accidental intra-arterial (IA) injection of drugs is between 1 in 3,440 and 1 in 56,000 anesthetics administered. The potential sequelae range from none to severe tissue necrosis necessitating amputation. All anesthesia providers should be aware of risk factors, signs and symptoms, available therapeutic modalities, and preventive measures for IA drug injection during anesthesia. Commonly used anesthetic drugs and their inadvertent IA injection effects are shown in Table 35.1.

## Risk Factors for IA Injection

- Patients who are unable to report pain on injection: patients receiving general anesthesia, comatose patients; patients with altered mental status; and very young pediatric patients.
- Pre-existing vascular anomalies of the forearm—insertion of catheter in artery rather than vein. The most common arterial anomaly of the upper limb is a high-rising radial artery resulting in a superficial branch (prevalence 1% to 14%). This anomaly results in the radial artery terminating in a thin superficial palmar branch that can be mistakenly cannulated (Fig. 35.1, Left). Another common anomaly (1% prevalence) is the antebrachialis superficialis dorsalis artery (Fig. 35.1, right). The radial artery bifurcates in the forearm, resulting in an anomalous superficial branch between the index finger and thumb. Often, this branch will cross underneath a terminal branch of the cephalic vein, just superficial to the radial styloid process—a common site for insertion of intravenous (IV) catheters (colloquialized as “intern vein”). Typically vigilant provider will recognize arterial insertion—based on pulsatile flow from the catheter while connecting to IV tubing, and/or backing of the pulsatile blood flow into intravenous tubing.
- High-risk anatomic locations, where arteries and veins lie in close proximity.
  - Antecubital fossa: brachial artery may be cannulated rather than the median basilic

vein.

- Groin: femoral artery cannulation rather than femoral vein.

- Multiple infusions through several vascular access lines with numerous ports (patients in the intensive care unit).
- Miscellaneous factors. Morbid obesity, darkly pigmented skin, multiple attempts at line placement, placement of lines under suboptimal conditions (attempts to insert the central line expediently during operations, in emergency situations and without ultrasonographic guidance), those with a pre-existing arterial or venous catheter who present for urgent resuscitation (trauma or urgent/emergent reoperation).

**Table 35.1 ■ Effects of IA Injection of Commonly Used Anesthetic Agents**

| Drug | Effect of IA Injection |
|---|---|
| Midazolam | Initial discoloration but no long-term effect |
| Promethazine, chlorpromazine | Gangrene |
| Thiopental | Chemical endarteritis, immediate vasoconstriction, thrombosis, tissue necrosis, endothelial cell destruction |
| Methohexital | Gangrene |
| Etomidate | No reports of necrosis |
| Ketamine | Proximal skin necrosis |
| Propofol | Pain, cutaneous hyperemia, no adverse sequelae |
| Lidocaine | Used therapeutically, no adverse effects |
| Penicillin | Gangrene |
| Cefazolin, ceftazidime | Arteriospasm and distal necrosis |
| Meperidine | Gangrene |
| Fentanyl | Upper extremity hyperemia |
| Sodium bicarbonate | Edema, erythema, pain; tissue necrosis |
| Metoclopramide | Discoloration but no long-term effect |
| Phenytoin | Cyanosis, digital artery occlusion, gangrene |

| | |
|---|---|
| Atracurium | Marked ischemia but full recovery |
| Rocuronium | Upper extremity hyperemia and decreased capillary refill |
| Succinylcholine | None-reported |
| Vecuronium | No adverse effects reported with prompt treatment |
| Dextrose solution | Gangrene |
| Dexmedetomidine | No adverse effects reported |
| Adenosine | Transient digital pain, hyperemia, mottled skin |
| Paracetamol (acetaminophen) | Digital pain, ischemia, and necrosis requiring amputation |
| Cocaine and flunitrazepam tablets | Arterial thrombosis and digital necrosis |
| Midazolam and pethidine (meperidine) | Skin erythema and pain |
| Diazepam | Digital necrosis requiring amputation |
| Promethazine | Tissue and digital necrosis requiring amputation |
| Epinephrine | Vasoconstriction, necrosis |
| Phenylephrine, succinylcholine, and red blood cell transfusion | Mottling of hand that resolved |
| Neostigmine and atropine/glycopyrrolate | No adverse effects reported |
| Fluorescein and indocyanine dyes | Arm pain and temporary discoloration |
| Calcium chloride | No adverse effects reported<br>Used therapeutically to localize insulinoma |
| Parenteral nutrition | Thrombosis |

IA, intra-arterial.

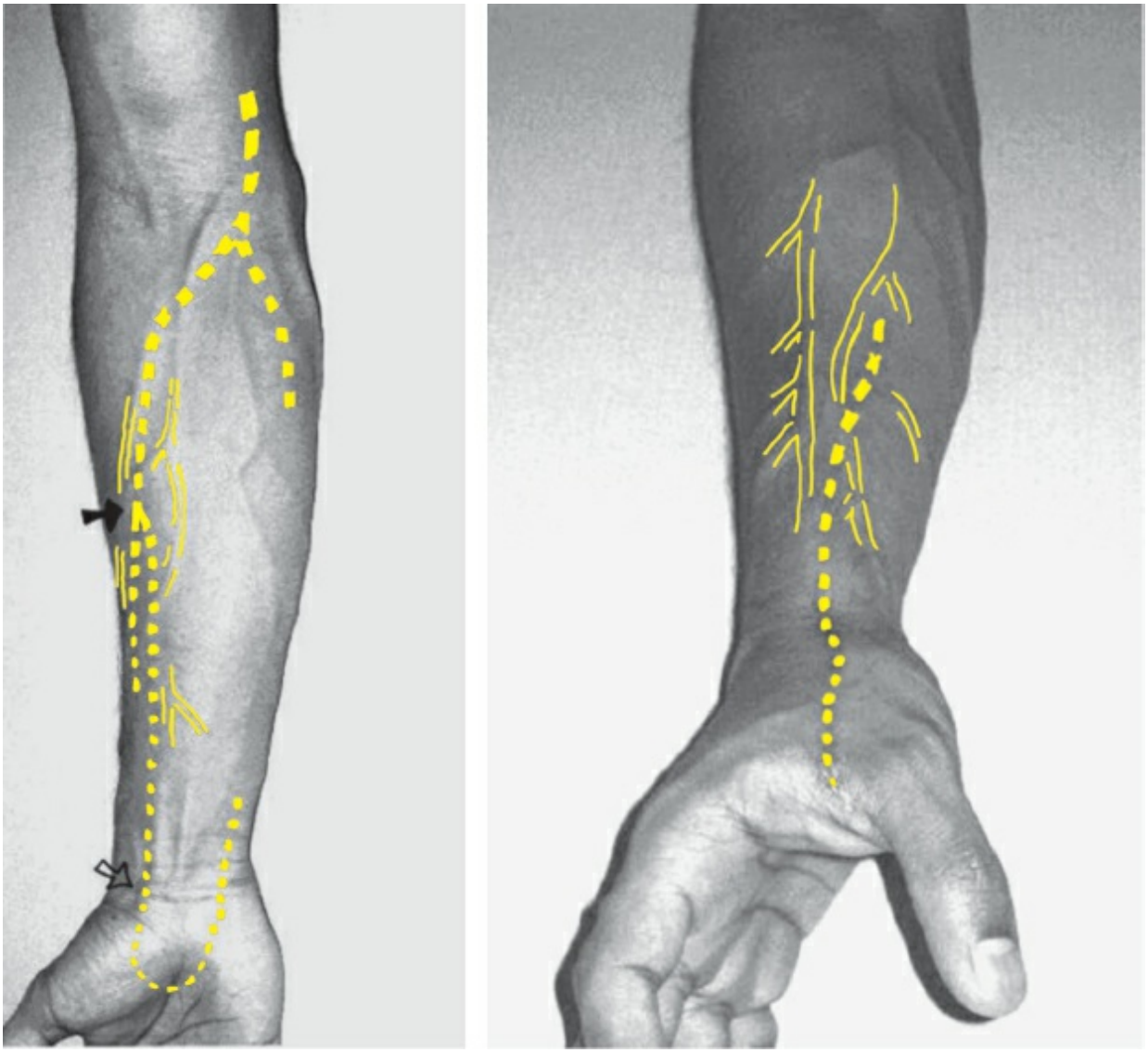

**Figure 35.1.** Vascular anomalies of the forearm. **Left:** Thick dotted line shows abnormal artery. Open arrow, normal branching point of radial artery; closed arrow, anomalous high-rising radial artery. **Right:** Thick dotted line shows anomalous antebrachialis superficialis dorsalis radial artery. Thin yellow lines show typical venous pattern. The abnormal artery course is in close proximity to commonly cannulated veins. (Reprinted from Sen S, Chini EN, Brown MJ. Complications after unintentional intra-arterial injection of drugs: risks, outcomes, and management strategies. Mayo Clin Proc. 2005;80(6):783–795. )

## Signs and Symptoms of Arterial Cannulation

- Bright red backflow and/or pulsatile blood into an IV tubing. However, judging the type of cannulation (arterial vs. venous) from the color of the blood (dark red vs. bright red) may be deceiving
- Backflow of blood into the IV tubing, even with the fluid bag at a higher level than the catheter insertion site
- Distal (e.g., nail bed) signs of ischemia (pallor) and skin mottling with "IV" fluid bolus

- Greater-than-expected pain with injection

If there is any doubt regarding the catheter site (i.e., arterial vs. venous insertion), confirm placement by transduction or drawing a sample for blood gas determination of oxyhemoglobin saturation.

## Pathophysiology

Although the underlying pathophysiologic mechanisms to explain the sequelae of an IA drug injection remain unclear, a few concrete conclusions can be drawn.

- Not all medications cause ischemia and tissue necrosis by the same mechanism. Some may cause crystallization and mechanical blockage of blood flow, whereas others may be directly toxic to the endothelium.
- Regardless of the mechanisms involved, thrombosis seems to be the common endpoint.

## Treatment Options

Most treatment modalities are based on maintaining distal perfusion to the involved extremity. Management should be based on the following principles:

- Immediately discontinue administration of the offending agent
- Cessation or reversal of arterial spasm
- Maintaining or reestablishing blood flow to distal extremities
- Treatment of any sequelae of vascular injury or ischemia (edema, compartment syndrome, infection, necrosis, gangrene)
- Symptomatic relief

**Step 1: Maintain the IA Catheter in Situ.** When an inadvertent IA injection occurs, the first instinct may be to remove the catheter, but maintaining the arterial catheter may have several advantages. The catheter should be cleared of any remaining drug, either by opening the catheter to the atmosphere to allow backflow of blood or by simply aspirating with a syringe. This should be followed by slow infusion of heparinized saline to help maintain catheter patency. Maintaining the IA catheter will also allow immediate delivery of specific diagnostic and treatment modalities to the site of injury, including contrast dye for angiography.

**Step 2: Identify Potential for Severity of Injury.** Certain clinical indicators can be roughly correlated with progressive tissue injury. Treiman et al. developed a "tissue ischemia score" based on signs and symptoms at presentation of 48 patients with IA injections. Patients were assigned a 0 for the absence or a 1 for the presence of four symptoms: cyanosis, cool extremity, delayed capillary refill, and sensory deficit. Of patients who had a tissue ischemia score of 2 or lower, 92% had a normal outcome. Of

patients who had a score higher than 2, only 41% had a normal outcome in the involved extremity; the others had tissue necrosis or permanent neurologic dysfunction.

**Step 3: Initiate Anticoagulation.** Administration of heparin seems to be broadly accepted as the initial treatment of IA injections. There is no consensus on the initial bolus amounts to use, appropriate target ranges for the activated partial thromboplastin time (aPTT), or duration of therapy, but an initial loading dose of heparin to achieve aPTT goals of 1.5 to 2.3 times higher than normal seems prudent. Of course, this must be balanced against the risk of postoperative bleeding and should take into account the patient's medical history, the operation performed, and current hemostasis. The duration of therapy can then be guided by resolution of symptoms, angiographic evidence of clot resolution, or the need for surgical intervention.

**Step 4: Symptomatic Relief.** Increased sympathetic vascular tone, edema distal to the site of injury, muscle injury or forced flexion contractures, temperature hypersensitivity, and paresthesias may all contribute to ongoing pain. Multiple case reports suggest that analgesics, extremity elevation, massage, and passive motion devices can be critical to treatment and recovery.

**Step 5: Other Interventions.** After implementing the first four steps, it is important to determine whether any other specific intervention is needed. The following interventions have been used with varying degrees of success:

- Local anesthetic injection: IA lidocaine to prevent or treat reflex vasospasm
- Extremity sympatholysis: stellate ganglion/axillary plexus blocks
- Arterial vasodilators: calcium channel blockers (nicardipine)
- Thromboxane synthase inhibitors: topical aloe vera, methimazole, and aspirin
- Iloprost: a prostacyclin analog used for various ischemic conditions
- IA papaverine: induces vascular smooth muscle relaxation by increasing intracellular cyclic adenosine monophosphate levels
- IA thrombolytics
- Hyperbaric oxygen therapy
- Corticosteroids: mainstay of treatment for any condition involving inflammation.
- Finally, if the larger-bore arterial catheter was placed inadvertently, removing the catheter may also require surgical intervention to repair the artery, as sometimes even prolonged compression of punctured artery may be an inadequate to stop the bleeding.

## Prevention of IA Injection

- Be aware of the risk and maintain a high index of suspicion when placing any intravascular catheter, particularly in antecubital and cephalic veins, and in patients at risk.
- Look for signs of arterial cannulation as outlined above.

- Use caution and maintain an index of suspicion with all pre-existing lines.
- Palpate target veins before IV placement.
- Do not tie a tourniquet tight enough to occlude arterial flow.
- Remove unnecessary injection ports or stopcocks. If an injection port is necessary, keep it as close to the patient as possible.
- Clearly label all arterial lines and all injection ports.
- Color code lines and injection ports.
- Trace each extension line back to the site of the cannula before injecting any medications.

Fikkers et al. reported a case of intentional IA cannulation as a viable route of administration of isotonic fluids and some select drugs when IV cannulation proved impossible. However, there clearly exists the potential for harm with IA-administered medications. Even in the presence of case reports demonstrating no adverse sequelae from IA injection of a given medication, we strongly caution against equating this to adequate "evidence" of safety to justify intentional IA of drugs intended for the IV route. Additionally, given the increasing use of ultrasound for placement of peripheral or central venous access as well as intraosseous access devices, we vehemently oppose intentional IA administration of drugs intended to be administered intravenously in all but the most extreme circumstances.

Despite recognition of accidental IA injections for many decades, these cases continue to occur. As always, the best solutions are prevention and continuous vigilance. Clinicians should be aware of risk factors for IA injection, the associated signs and symptoms, the underlying pathophysiology, and available treatment options. Such awareness will help decrease the incidence, delays in diagnosis, and resulting complications of this medical error.

## TAKE HOME POINTS

- IA injection occurs when a venous line is inadvertently placed in an artery without recognition or because of inadvertent injection into the arterial line.
- Develop techniques for ensuring that venous and arterial lines and/or stopcocks are clearly labeled (e.g., red and blue tape at injection ports, etc.). Minimize the existence or number of arterial ports.
- Do not automatically remove the catheter if there is an inadvertent IA injection.
- Start treatment as soon as possible.
- Inform the necessary personnel what has happened (surgeons, patient, legal, etc.).

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36

# Do Not Use the Subclavian Vein for Central Access of Any Type in a Patient Who Is On or Planned for Dialysis

Catherine Marcucci, MD and Michael J. Moritz, MD FACS

There are about 470,000 hemodialysis (HD) patients in the United States today, and the number is increasing by about 4% to 5% annually. The increasing incidences of diabetes mellitus and hypertension, and the relative scarcity of renal transplants (still only about 10,000 annually in the United States) mean that HD will continue to be required. For many patients who will never receive a transplant, HD must be considered a lifelong treatment. Because the critical nature of vascular access for HD is amplified by length of time on treatment, provision and maintenance of vascular access will remain one of the greatest problems in dialysis medicine.

In the most optimal situation, permanent dialysis access is placed in advance of dialysis. There are three main types of long-term HD access: native arteriovenous fistula, arteriovenous graft, and central venous catheter. It's great if your patient has one of these that is functioning well and the surgery is not a big one. Then all you have to do is not do anything that "bothers" the HD access and both you and the patient should be fine. However, not infrequently, the anesthesiologist will be faced with two significant access problems in renal failure and dialysis patients: the patient with renal failure needs acute access placed for perioperative HD or the patient who is on or planned for dialysis needs central venous access for a big surgery or ICU admission. In both situations, it is imperative that the subclavian veins not be broached if at all possible.

In the first situation, patients present with an acute need for dialysis that requires temporary dialysis access via a percutaneous catheter. Anesthesiologists will usually be confronted with this situation as part of the intensive care management of a patient. If there is any thought that the patient may go on to require chronic dialysis, it is imperative that the temporary access not compromise the vasculature. Temporary percutaneous dialysis catheters are associated with significant damage to the cannulated vein, and there is a very real risk of acute or delayed thrombosis or stenosis of the vein.

The preferred sites for temporary HD access catheter placement are the internal

jugular (IJ) veins or the femoral veins—not the subclavian veins. In a 2014 review article, Santoro et al. covered the issues in depth. The IJ vein is prioritized as it is a large and relatively superficial vein that is easily visualized on ultrasound (which of course, is a must). The IJ has a straight course to the superior vena cava and right atrium, so allows for high blood flow during HD. It is considered to be only a medium-risk for bleeding and infection. The femoral veins are a higher infection and thrombosis risk and HD access placed in these vessels does not function as well when the patient is sitting. However, there is a lower bleeding risk with placement. The subclavian vein should be avoided unless absolutely necessary. Due to its position behind the clavicle, it is considered a blind procedure. There is a higher bleeding risk, higher pneumothorax risk, and higher thrombosis risk.

For example, dialysis catheters in subclavian veins have been associated with a rate of thrombosis/stenosis of 50% to 70%, versus 0% to 10% for catheters placed in the IJ veins. Patients with subclavian vein occlusion may have spontaneous recanalization after 3 to 6 months and can also be treated with angioplasty and stent placement, but the vein will never be completely normal. Remember that permanent HD access involves an arterial-to-venous connection, either as a fistula (direct artery-to-vein connection) or with a prosthetic graft between the artery and vein. The longest-lasting and most successful access is placed in the upper extremity because of lower infection rates and better patient comfort. Permanent HD access will create high flow through the vessels of the upper extremity, and the success and function of the site is highly dependent on adequate venous outflow from the access site to the right atrium. Decreased venous outflow can also create profound edema that can be limb-threatening.

In the second situation in which a patient who receives or is planned for HD needs a central access during the perioperative course, the same holds true. Although the risk of injury to the subclavian vein is less with smaller catheters such as sheaths for pulmonary artery catheters and triple- or single-lumen central lines, subclavian vein cannulation with these lines should be avoided for the same reasons. Remember that subclavian thrombosis or stenosis (even if clinically silent) results in loss of all potential access sites in the ipsilateral extremity.

## TAKE HOME POINTS

- Many renal failure patients will never receive a kidney transplant and will require lifelong dialysis.
- Temporary access secured in the perioperative period for dialysis and other reasons must not compromise the vasculature of the upper extremity.
- For this reason, catheters (especially dialysis catheters) should be preferentially

placed in the IJ veins.

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# Consult the Surgeons Immediately if Your Patient Loses a Patent Hemodialysis Fistula—This Is a Serious Complication for the Patient

Steven J. Busuttil, MD

Chronic renal insufficiency/failure (CRI/F) is a leading cause of morbidity and mortality in a growing percentage of the US population. Most causes of end-stage renal disease stem from two major comorbid conditions—diabetes mellitus and hypertension. The ultimate end result of CRF is reliance on hemodialysis for maintenance of renal function. The use of hemodialysis fistulas has both improved the quality and prolonged the lives of CRF patients, although there are associated complications (Table 37.1).

## Hemodialysis Fistulas

Hemodialysis fistulas or ports for dialysis are surgically created communications between the native artery and vein in an extremity. Direct communications between artery and vein are called native arteriovenous fistulas (AVFs). Polytetrafluoroethylene (PTFE) and other materials (Dacron, polyurethane) are used or have been used as a communication medium between the artery and the vein and are termed prosthetic hemodialysis access arteriovenous grafts (AVGs). The patency rates for AVFs are about four times greater than for AVGs. The access that is created is routinely used for hemodialysis two to five times per week. Preservation of a patent well-functioning dialysis fistula is one of the most challenging issues for the dialysis patient. As many as 25% of hospital admissions in the dialysis population have been attributed to vascular access problems, including fistula malfunction and thrombosis.

**Table 37.1 ■ Complications of Hemodialysis Fistulas**

- Hemodynamic complications—congestive heart failure
- Arterial steal syndrome
- Carpal tunnel syndrome

- Infection
- Noninfectious fluid collections—seroma, lymphocele, hematoma
- Aneurysm, pseudoaneurysm

In fact, only 15% of dialysis fistulas remain patent and can function without problems during the entire period of a patient's dependence on hemodialysis. The majority of patients who have native fistulas placed will be problem free with their fistulas for a mean of 3 years after creation, whereas prosthetic PTFE grafts usually last only about a year before indications of failure or thrombosis are noted.

Long-term secondary patency rates are reportedly 7 years in the forearm, 3 to 5 years in the upper arm for native fistulas, and about 1 year for prosthetic grafts after multiple interventions to treat the underlying stenosis and thrombosis.

## AVF Failure

The underlying cause of AVF failure in the nonacute setting or outpatient setting is invariably thrombosis due to venous anastomosis in prosthetic grafts or anastomosis of the outflow vein in native fistulas (Table 37.2). The pathophysiology behind this failure is the eventual intimal hyperplasia at the anastomosis site. Future therapy is directed at halting the intimal growth of anastomotic vessels, using technology similar to that employed with drug-eluting cardiac stents.

The main cause of AVF thrombosis in the acute care setting, particularly the perioperative period, is almost always low flow, usually caused by hypotension and/or poor cardiac output. A sudden decrease in blood pressure can lead to platelet aggregation, sledging, and eventual thrombosis. An important secondary cause for the loss of a patent fistula is excessive external pressure on the AVF, usually as a result of monitoring or positioning. Remember also that surgical patients are in a hypercoagulable state—this may also predispose to thrombotic events.

It is imperative that anesthesia providers recognize the clinical signs of impending AVF thrombosis. It is wise to evaluate the fistula as thoroughly as possible before starting the anesthetic. Remember that dialysis patients are often the best source for information on their personal fistula histories.

**Table 37.2 ■ Causes of AVF Thrombosis**

- Poor cardiac outflow (hypotension)—sudden decrease in blood pressure can lead to platelet aggregation, sledging, and eventual thrombosis

- Excessive pressure on AVF (blood pressure measurement)
- Hypercoagulable state
- Progressive inflow stenosis
- Venous outflow stenosis

Clinical signs of impending AVF thrombosis include the following:

- Loss of thrill
- Increased pulsatility (water-hammer pulse)
- Direct palpation of stenosis
- Insufficient inflow, such as stenosis in the supplying native artery or proximally in the subclavian or brachiocephalic artery
- Identification of high venous pressures or low flow according to the protocol provided by the specific type of hemodialysis machine—try to ascertain whether there were problems with the duration of treatment or volume of fluid removed in the last dialysis run before surgery
- Ipsilateral arm edema and/or collateral venous pathways suggestive of a central venous stenosis

Similarly, the care of AVFs during anesthesia requires the very close attention of the practitioner:

- Maintain normotension—hypotension may lead to clot formation and thrombosis.
- Maintain heart rate—symptomatic bradycardia may decrease coronary output and lead to thrombosis.
- Do not place the noninvasive blood pressure cuff on the AVF arm—compression can limit inflow/outflow and promote thrombosis.
- D o not perform venipuncture on the AVF arm—local clotting factors may favor thrombosis. If you get stuck for sites for line placements, consult with the surgeons and/or vascular surgeons before the start of the operation. Emergency situations may involve broaching the integrity of the vasculature of the extremity that has the fistula—if so, expect that the fistula may be lost and make proactive plans.
- Actively feel and document presence of a thrill at regular intervals during the procedure—presence confirms a functioning AVF.
- Consider regional anesthesia when appropriate to minimize fluctuations in blood pressure and heart rate.
- Document the thrill when signing the patient out in the PACU or ICU.
- Communicate immediately with the surgeon if there is a change in AVF status (this usually means the loss of the thrill).

## Treatment of AVF Thrombosis

Unfortunately, thrombosis of dialysis access is not an uncommon event during the perioperative period. Historically, treatment of AVF thrombosis involved surgical thrombectomy with ongoing hospital admission. Typically, surgical treatment resulted in sacrificing a portion of the outflow vein.

Multiple treatment options are now available and depend on the patient's comorbid conditions, the availability of the appropriate surgical personnel, the availability of radiologic support, and previous fistula treatment (Table 37.3). Often, a radiologic intervention is considered most favorable, if possible. Patients may thus sometimes go directly from the PACU to interventional radiology. Alternatively, other dialysis access, such as a double-lumen Shiley, may be placed in the immediate postoperative period. Occasionally, treatment is deferred until the patient is clinically and hemodynamically stable.

**Table 37.3 ■ Treatments**

- Thrombolysis
  - With angioplasty
  - Without angioplasty
- Percutaneous thrombectomy
  - With angioplasty
  - Without angioplasty
- Surgical thrombectomy
  - With revision
  - Without revision

### TAKE HOME POINTS

- Native AVFs are less prone to thrombosis than grafts.
- Loss of the graft is a serious perioperative event for the patient.
- Low flow states caused by hypotension, low cardiac output, and external compression are the most significant causes of fistula thrombosis. If there is a new or existing hemodialysis fistula, think carefully before lowering the blood pressure aggressively with propofol, labetalol, or hydralazine.
- Maintain high vigilance for hemodynamics and positioning.

- Don’t be afraid to consult the surgeons about the preferred sites for both venous and arterial line placement.
- Check for the thrill at regular intervals and let the surgeons know immediately if the thrill is lost.
- One final point—what you feel when lightly palpating the fistula is not a bruit—by definition, a bruit is an abnormal sound heard when placing a stethoscope over an artery.

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## SECTION III

# FLUIDS AND RESUSCITATION

38

# Introduction

Brian T. Gierl, MD and Catherine Marcucci, MD

The electronic record provides the ability to generate large amounts of data for analysis, which has identified differences in outcomes that are influenced by decisions that one might make with very little forethought, or afterthought for that matter. This section breaks down the rough science behind fluid and volume selection and makes recommendations for anesthesia practice.

We all know that intravascular volume status is the usual determinant of preload and an essential component of cardiac output. But volume overload can lead to edema—in the periphery, the brain, the pulmonary vasculature or even the bowel. Protocols that limit bowel edema have been shown to reduce postoperative length of stay in many abdominal surgeries. But hypovolemia is associated with acute kidney injury (AKI) and we now know that cumulated AKI leads to chronic renal failure. And that allowing clear liquids improves both satisfaction and outcomes in many patient populations—so the right volume of fluid is good.

When you choose the right volume of fluid—which patient should receive crystalloid or colloid? Colloid fluids were all the rage… until they were associated with platelet dysfunction and renal injury. Then the starches were reformulated. Read on to find the current evidence. There is a reason that at many hospitals, intravenous fluids are stocked through the pharmacy.

The subsequent chapters will describe all of the details of our commonly used intravenous fluids—the pH and sodium content of 0.9% NaCl, Ringer Lactate and PlasmaLyte A. We describe how "Normal Saline" is abnormal in many ways when compared to your plasma. The idea of "Strong Ion Difference" (SID) as the driver for hyperchloremic metabolic acidosis is introduced. An analysis by SID shows that 1 g of Calcium Chloride is very different than the "equivalent" 3 g of Calcium Gluconate. You will likely never look at a bag of clear fluid the same way again.

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# Crystalloid Fluids: More Than Just a Dash of Salt

Sephalie Patel, MD and Brian T. Gierl, MD

A homeless man is found unresponsive during a heat wave and brought to the emergency department by medics. He is stuporous and tachycardic, and complains of abdominal pain. A scan demonstrates pneumoperitoneum and he is transferred to the preop area for an exploratory laparotomy. During preinduction he received a total of 5 L of 0.9% NaCl and his tachycardia resolved. After induction, you place an arterial line and send an arterial blood gas that shows a pH of 7.0, $PaCO_2$ 35 mm Hg, $Na^+$ 149 mEq/L, $Cl^-$ 120 mEq/L, and lactate 4 mEq/L. What is the source of this acidosis?

**Table 39.1 ■ Composition and Characteristics of Human Plasma and Common Crystalloid Solutions for Intravenous Resuscitation of Homo Sapiens**

| Entity | Plasma | Normal Saline | Lactated Ringers | Plasma-Lyte A |
|---|---|---|---|---|
| $Na^+$ (mEq/L) | 135–145 | 154 | 130 | 140 |
| $K^+$ (mEq/L) | 4.0–5.0 | 0 | 4.5 | 5 |
| $Ca^{2+}$ (mEq/L) | 2.2–2.6 | 0 | 2.7 | 0 |
| $Mg^{2+}$ (mEq/L) | 1.0–2.0 | 0 | 0 | 1.5 |
| $Cl^-$ (mEq/L) | 95–110 | 154 | 109 | 98 |
| Acetate (mEq/L) | 0 | 0 | 0 | 27 |
| Lactate (mEq/L) | 0.8–1.8 | 0 | 28 | 0 |
| Gluconate (mEq/L) | 0 | 0 | 0 | 23 |
| Bicarbonate (mEq/L) | 23–26 | 0 | 0 | 0 |
| Osmolarity (mOsm/L) | 291 | 308 | 280 | 294 |
| pH | 7.4 | 5.5 | 6.75 | 7.4 |
| SID (mEq/L) | 24[a] | 0 | 28 | 29[b] |
| Cost (USD)[c] | ~$250 | ~$1.20 | ~$1.50 | ~$5.00 |

[a]Plasma SID is considered to be 24 mEq/L as a basis of comparison to balanced crystalloid solutions. A solution with an SID >24 mEq/L is relatively alkylotic as compared to plasma, while a solution with an SID <24 mEq/L worsens acidosis.
[b]The equilibrium with acetate and gluconate makes the effective SID of Plasma-Lyte A ~29 mEq/L, which is much less than the calculated SID of that solution.
[c]Costs of crystalloid solutions from Google Shopping, November 2017.

Crystalloid fluids are ubiquitous and cheap, but their composition varies greatly and the choice of fluid can significantly affect patient outcomes. Two types of crystalloids are used today, 0.9% NaCl is the default solution and known as "normal" saline, while the "balanced" salt solutions replace some of the sodium and chloride with other ions to produce a solution that is physiologically closer to that of the plasma of a healthy homo sapien than to seawater. Recall that no matter how dehydrated you are, drinking seawater (~3.5% NaCl) only further dehydrates you. Table 39.1 lists the compositions and characteristics of human plasma and the commonly used crystalloid solutions: 0.9% NaCl, Plasma-Lyte A (equivalent to Normosol A), and lactated Ringer's.

What could be better than saline, you ask? Well 0.9% NaCl is slightly hypertonic and very hyperchloremic relative to our usual plasma and very acidic with a pH of 5.5—making "normal" saline quite abnormal as compared to plasma. Infusing large volumes of 0.9% NaCl results in a hyperchloremic metabolic acidosis due to the large strong ion difference (SID) of 0.9% NaCl. Traditionally, the acid–base equilibrium and the pH of blood were attributed entirely to the bicarbonate concentration per the Henderson–Hasselbach equation. However, Stewart more appropriately demonstrated that the pH of physiologic solutions depends upon the SID, weak acid concentration (albumin and

$PO_4^{3-}$) and partial pressure of carbon dioxide (PCO2).

$$SID = [Na^+] + [K^+] + [Ca^{++}] + [Mg^{++}] - [Cl^-]$$

Plasma SID is considered to be 24 mEq/L as a basis of comparison to balanced crystalloid solutions. A solution with an SID >24 mEq/L is relatively alkylotic as compared to plasma, while a solution with an SID <24 mEq/L worsens acidosis.

Lactated Ringer solution replaces some of the chloride with lactate and the 28 mEq/L of lactate is why LR has an SID of 28 mEq/L. The weak anions gluconate and acetate play a similar role to give Plasma-Lyte A a pH of 7.4 and an estimated effective SID of 30 to 40 mEq/L. The actual SID of Plasma-Lyte A is impacted by a complex equilibrium between the weak anions, but an SID >24 mEq/L will push the pH toward 7.4.

Several studies have evaluated whether diluting pRBCs with LR causes the blood to clot. Recall that pRBCs are in a citrate solution that binds the free calcium that is necessary to facilitate the coagulation cascade. The calcium in LR (2.6 mEq/L) is insufficient to overcome the citrate present in pRBCs based on three different studies. However, the FDA's Circular of Information for Blood Products still lists diluting blood products with LR as an absolute no-no. And Canadian Blood Services agrees with the FDA. Diluting pRBCs with 0.45% NaCl (half-normal saline) will lead to RBC lysis. You will infuse a lot of free hemoglobin and potassium.

What solution is appropriate for hyperkalemic patients? Contrary to popular belief, 0.9% NaCl will increase potassium concentration while LR and Plasma-Lyte A only increase plasma potassium when the patient is hypokalemic or both hyperkalemic and alkylotic. Recall that a great majority of total body potassium is intracellular. Potassium shifts into and out of cells to maintain electroneutrality when hydronium ions ($H^+$) shift into and out of those same cells to maintain extracellular pH. The majority of hyperkalemic patients are acidotic and the shift of $H^+$ into cells causes $K^+$ to shift into the plasma. Balanced fluids with an SID greater than 25 mEq/L increase pH and shift $K^+$ back into cells. O'Malley et al. found that renal transplant patients receiving LR versus NS are less likely to require bicarbonate therapy and develop hyperkalemia.

So, if balanced fluid is good, how much should the patient receive? And are goal-directed therapy protocols to titrate cardiac preload and intravascular volume with sytemic vascular resistance and myocardial contractility to optimize end-organ perfusion valid? The choice of fluid for that optimization introduces the concept of the endothelial glycocalyx, an albumin- and carbohydrate-rich layer that is bound to the capillary surface by glycoproteins. It is an important portion of the vascular barrier and its breakdown increases vascular permeability and exposes platelets to endothelial

components that promote clot formation. Hypervolemia dilutes the glycocalyx, which leads to edema formation and aberrant clot formation. Thus, too much of any fluid can have consequences. While some studies found that the infusion of albumin or hydroxyethyl starch preserved or improved the thickness of the glycocalyx, neither have been shown to consistently improve patient outcomes. Realize that while the common 5% albumin solutions may help to preserve the glycocalyx, they are dissolved in NaCl with an SID of 0 which worsens acidosis.

## The Evidence

Studies have shown a lower rate of complications (infection, renal replacement therapy, blood transfusion, and acidosis) with use of Plasma-Lyte A over 0.9% NaCl for fluid replacement on the day of surgery. Additionally, use of a chloride-restrictive fluid strategy decreased the incidence of acute kidney injury (AKI) in Australian ICU patients without altering in-hospital mortality, hospital or ICU length of stay. From these studies, we conclude that administering large volumes of 0.9% NaCl is detrimental to patients who receive large volume resuscitation or are at high risk of a range of complications. The broad use of balanced crystalloids versus 0.9% NaCl in relatively healthy ASA I and II patients not requiring large volume resuscitation has not been demonstrated; the impact of fluid choice on the clinical outcomes of healthy people who present in a near euvolemic state is minimal or perhaps nonexistent.

Balanced salt solutions are hypotonic as compared to plasma due to the lower concentration of sodium, which can be detrimental to patients who present with hypernatremia or patients who are receiving hyperosmolar therapy for intracranial hypertension.

Infusion of LR can lead to elevated lactate levels in patients with impaired lactate clearance (sepsis, hepatic insufficiency) and when large volumes are used. Care should be used when drawing blood samples to avoid a location near the LR infusion. Whenever a large volume resuscitation occurs, serial laboratory values should be examined to identify electrolyte disturbances that can be treated. Underperfusion is the most common etiology of elevated lactate levels. Unlike in underperfusion, elevated lactate levels due to the administration of LR are not detrimental and treatments typically used for underperfusion (fluids, inotropes) are not appropriate for this type of hyperlactatemia.

Balanced salt solutions cost more than 0.9% NaCl. Plasma-Lyte A costs ~4× that of 0.9% NaCl, which is impressive. However the utilization of Plasma-Lyte A for an additional ~$4.00 per liter during the acute resuscitation phase is easily recouped if the provider sends one fewer blood gas to analyze an acidosis. The number needed to treat (NNT) with Plasma-Lyte A versus 0.9% NaCl to prevent a meaningful complication that

has a known associated cost is not clear, making a cost–benefit calculation difficult.

## The Practice

In practice, for an adult with normal hepatic and renal function, infusing up to 40 cc/kg of 0.9%NaCl will not significantly alter acid–base status. The limit for patients with comorbidities and active illnesses that cause acidosis are not well defined, but there is very limited downside to the administration of balanced salt solutions in place of 0.9% "abnormal" NaCl; aside from cost.

In the vignette that started the chapter, our patient received a large volume of 0.9% NaCl to treat his metabolic acidosis. One might argue that the resuscitation may have contributed to his acidosis. Regardless of judging the benefits of the 0.9% NaCl, it is reasonable to conclude that his acid–base status might be much closer to the physiologic norm of 7.4 if he would have received a similar volume of a "balanced" salt solution. The evidence shows that he would be less likely to experience AKI if he had received a "balanced solution" as well.

### TAKE HOME POINTS

- "Normal" saline is not a physiologic match to plasma!
- Infusing large volumes of 0.9% NaCl will lead to a hyperchloremic metabolic acidosis and can lead to worse outcomes, specifically AKI in susceptible patients.
- Balanced crystalloid solutions are increasingly recommended as first-line resuscitation fluids in surgical and trauma patients.
- The administration of large volumes of crystalloids will cause the glycocalyx to breakdown, leading to edema formation and aberrant activation of the coagulation cascade. But 5% albumin is diluted in 0.9% NaCl with an SID of 0 mEq/L.
- Lactated Ringer solution contains a small amount of calcium that is insufficient to cause clot formation when used to dilute pRBCs.

## Suggested Readings


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40

# Hypertonic Saline: Still the "Solution" to the Solution Problem?

Lavinia Kolarczyk, MD, Colleen Moran, MD, and Patrick J. Forte, MD

Analogous to the variety of beverages in your supermarket's soda aisle, there exist numerous choices for fluids for patients. What is best for your patient's needs? What fluid is appropriate for specific situations? How much fluid should be administered? Although these questions may seem trivial, the knee-jerk reflex for most residents is to use a fluid that they feel most comfortable administering. Let us wade out of the "normal saline" pool and explore the clinical uses of hypertonic saline.

Fluids became the focus of prehospital resuscitation research more than 75 years ago. The same clinical problems encountered with fluid resuscitation efforts then remain the focus of today's research. The search continues for an "ideal" fluid, that is, one that is inexpensive, generates sustained hemodynamic effects with minimal peripheral or pulmonary edema, and is effective even in small volumes.

Traditionally, isotonic crystalloids such as lactated Ringer solution and normal saline have been considered first-line treatment for trauma patients. Although these fluids are inexpensive, readily available, nonallergenic, noninfectious, and efficacious in restoring total body fluid, they have limited intravascular half-life. A proposed solution to the "solution problem" is to augment the osmotic properties of traditional resuscitation fluids. In theory, this would extend the intravascular half-life and reduce the amount of third spacing. The "ideal" fluid search then focused on osmotic properties, and hypertonic saline (with and without colloid) became a prime subject of research.

Hypertonic saline already had a role in the trauma setting, as it was used for patients with increased intracranial pressure secondary to traumatic head injury. Of note, mannitol (an osmotic diuretic and cerebral arteriolar vasoconstrictor) was traditionally used as first-line therapy in this patient population, but it was associated with rebound intracranial hypertension. It was believed that this effect was due to intravascular dehydration and an inability to maintain cerebral perfusion pressure when diuresis was not matched by appropriate fluid administration. Hypertonic saline became the agent of

choice, as it served a dual purpose as a diuretic and a resuscitative agent. In a battlefield setting, hypertonic saline has been suggested as a good alternative to normal saline for resuscitation since it is a smaller volume to carry.

Further research in the use of hypertonic saline in the trauma setting revealed that it had vasoregulator, immunologic, and neurochemical effects (Table 40.1). Hypertonic saline increases blood pressure and cardiac output secondary to plasma volume expansion, and it is also thought to stimulate adrenocorticotropin and cortisol release. Hypertonic saline is also believed to counteract vasospasm occurring after traumatic brain injury through its vasodilatory effects. On a molecular level, hypertonic saline has been shown to improve microvascular perfusion by attenuating leukocyte–endothelial interactions. It has also been suggested that hypertonic saline can provide protection from bacterial illness by attenuating changes in extracellular sodium and excitatory neurotransmitters that occur after injury. These changes are thought to depress leukocyte adherence and neutrophil margination.

**Table 40.1 ■ Hypertonic Saline: Beyond Plasma Volume Expansion**

| | |
|---|---|
| Vasoregulatory effects | Counteracts vasospasm occurring after traumatic brain injury through its vasodilatory effects. Improves microvascular perfusion by attenuating leukocyte–endothelial interactions. |
| Immunologic effects | Changes in extracellular sodium that occur after injury may be attenuated by hypertonic saline, which is thought to depress leukocyte adherence and neutrophil margination. |
| Neurochemical effects | Changes in excitatory neurotransmitters that occur after injury may be attenuated by hypertonic saline, which stimulates adrenocorticotropin and cortisol release. |

Although the most common concentration of hypertonic saline used clinically is 3%, the concentrations studied in clinical trials range from 1.7% to 29.2%. In spite of concern for hypertonicity, acute increases in serum sodium levels to 155 to 160 mEq have not been shown to be harmful to most patients. However, too rapid correction of hyponatremia can result in osmotic demyelination syndrome and permanent brain damage.

Another clinical problem with hypertonic saline is the transient nature of the

resulting hemodynamic improvement (30 to 60 minutes) when it is used as a resuscitative fluid, much like traditional resuscitative fluids. Proposed strategies to lengthen the hemodynamic effects of hypertonic saline include longer infusion times, subsequent or concomitant infusion of blood or conventional fluids, and adding 6% dextran to the hypertonic saline. Despite the claims surrounding the addition of colloid, there remains no clear answer as to the best strategy to lengthen hemodynamic effects of hypertonic saline.

The reality is that the clinical efficacy of hypertonic saline resuscitation versus conventional fluids remains unclear because many prehospital studies compared only single boluses of experimental and control fluids. Furthermore, misleading conclusions exist about the clinical responses to different types of fluid resuscitation (including hypertonic saline with and without colloid additives). This is likely the result of studies comparing two or more regimens that alter more than one variable.

In addition to the use of hypertonic saline in the prehospital and trauma setting, it has several well-established roles. These include the care of patients with severe, symptomatic hyponatremia (<115 to 120 mEq) and in the fluid management of critical burn injuries. Nontraditional uses of hypertonic saline include stimulation of expectoration, which has been implemented in the care of patients with cystic fibrosis and to prevent mucous plugs in ventilated patients. Hypertonic saline has also been used in the treatment of tricyclic antidepressant (TCA) toxicity. Rapid, cataclysmic clinical deterioration may occur shortly after TCA overdose. Traditionally, sodium bicarbonate is used to reverse TCA cardiotoxicity (dysrhythmias), but hypertonic saline has also been shown to do this. Furthermore, in the setting of hemodynamic instability generated by TCA toxicity, hypertonic saline may be especially useful for a hypotensive patient.

Support for hypertonic saline is growing in the prehospital and trauma setting based on recent research into its beneficial effects at the cellular and molecular levels. Hypertonic saline may come to be viewed as a "drug" instead of a simple fluid, which will bring about more research into the adequate "dose" and "timing of administration." This may ultimately clarify its clinical role and clear up the misleading conclusions that currently exist about its clinical efficacy in the trauma setting.

## TAKE HOME POINTS

- Hypertonic saline has documented vasoregulatory, immunologic, and neurochemical effects—it may come to be viewed more as a drug than a simple fluid.
- The use of hypertonic saline has been driven by the resuscitation issues encountered with burn, trauma, and critically ill patients. Seek out senior providers in these areas to gain clinical expertise.

- Limit increases of serum sodium to 10 mmol/L during the first 24 hours to a maximum serum sodium of 155 mEq.
- Hypertonic saline with concentrations of at least 3% should be administered via central access. If this is not available, 1.5% saline can be safely given through a peripheral IV.

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41

# Synthetic Colloid Solutions Have Distinct Properties and Risk/Benefit Ratios That Require Your Attention!

Lindsay M. Stollings, MD and Raymond M. Planinsic, MD FASA

Before an anesthesia provider can consider the colloid solutions in general and the hetastarch products in particular, he or she must first have an understanding of the basics of perioperative fluid therapy. Perioperative fluid therapy includes the replacement of pre-existing fluid deficits, maintenance requirements, and surgical losses.

Normal maintenance requirements (Table 41.1) are what the body requires to maintain adequate urine production, compensate for losses from the respiratory tract or skin, as well as gastrointestinal (GI) secretions. These losses are hypotonic, or in other words, have a lower osmolality than the cells in the body.

Fluid deficits may come from a variety of sources. First, the great majority of patients who come to the operating room have fasted for at least 6 hours. For the average 70-kg man this calculates to a deficit of (110 mL/hr × 6) or 660 mL. For many gastrointestinal (GI) procedures, patients may also get a preoperative bowel-cleansing preparation. This may increase fluid losses by 1 to 2 L. Increased insensible losses also occur as a result of increased sweating, respiratory losses from fevers, as well as any patient who has been breathing nonhumidified gases. Finally, patients who experience diarrhea, vomiting, diuresis, or bleeding will have fluid depletion as well as electrolyte disturbances. Estimating these pre-existing fluid deficits are more difficult to accurately quantify and recent studies have called into question these original methods for estimating these losses.

**Table 41.1 ■ Fluid Maintenance Estimates**

| Weight (kg) | Rate (mL/kg/hr) |
|---|---|
| 0–10 | 4 |

| | |
|---|---|
| Next 10–20 | 2 |
| Each kg >20 | 1 |

**Fluid Estimates Calculation**

Example 1. 100-kg person.

(10 × 4) + (10 × 2) + (80 × 1) =
140 mL/hr

Example 2. 23-kg child

(10 × 4) + (10 × 2) + 3 = 63 mL/hr

For surgical losses, the anesthesia provider must be vigilant, as underestimating surgical blood loss can have devastating consequences. The first obvious place to look is in the suction canister or at the sponges. Additionally, a 4 × 4 sponge may hold 10 mL of blood and a full-sized, soaked laparotomy pad may represent 100 mL of blood loss. Furthermore, one must account for the use of irrigation solution, and frequent communication between the surgical personnel when estimating this fluid is essential. With the increased use of cell salvage techniques, a second suction canister may be present. However, quick visual estimation of blood losses may account for only one-third of the "actual blood loss." There may be a significant amount left unaccounted for in tubing, on drapes or the floor, or on the gloves and gowns of surgical personnel. Once estimated, surgical blood loss replacement, not including the use of blood products, can occur in the ratio of 1:3 for crystalloid solutions and 1:1 for colloid solutions. For example, a 300-mL blood loss could be corrected by giving 900 mL of crystalloid or 300 mL of colloid.

But how does one decide whether to use crystalloid or colloid solutions and what are colloid solutions? Simply, colloid solutions are high–molecular-weight substances administered to maintain intravascular volume. They last intravascularly from 3 to 6 hours, up to six times longer than crystalloid solutions, such as normal saline or lactated Ringer's. Some indications for the use of colloid solutions are for fluid resuscitation prior to blood product availability or in patients with severe hypoalbuminemia. One must also consider the context of care, such as a critically ill patient in the intensive care unit versus the intraoperative setting, which is the focus of this chapter, as the risk/benefit profiles differ.

There are many different types of colloid solutions. One of the most familiar to anesthesia providers is albumin, which is available in 5% and 25% solutions. The albumin protein is relatively stable and is heated to 60°C for 10 hours to potentially remove pathogens such as HIV and hepatitis. Albumin is one of the most expensive

solutions, as it is derived from donated blood. Recently, the lower cost pentastarch and hetastarch (Hespan®) have been increasingly popular. Both are composed of glucose chains to which hydroxylated ethyl ether groups have been added in order to resist degradation. The average molecular weight of hetastarch is 450,000 kD, and comes in a 6% solution of either NaCl (Hespan®) or LR (Hextend®) (Table 41.2). Pentastarch, which has a slightly smaller molecular weight, was developed secondary to the fact that the large hetastarch molecules are sequestered in the reticuloendothelial system (RES), the kidney, and the liver. Although this has not been shown clinically, it may impair the RES. Outside the United States, but only since FDA approval in 2007, a tetrastarch (Voluven®) is available as well and recent analyses have suggested improved risk profiles as compared to hetastarches. For a comparison of hetastarch, pentastarch, and tetrastarch (all in NaCl solution) see Table 41.3.

The polyhydroxylated starches have relative contraindications in patients with coagulopathies, fluid overload, renal impairments, or those undergoing cardiac surgery, and produce rare hypersensitivity reactions. However, recent data and regulatory agencies continue to make clinical decision making difficult regarding hydroxyethyl starch use. Hetastarch has been shown to have a decreased inflammatory response compared to albumin preparations. However, there is evidence showing possible impaired coagulation with Hespan as compared to albumin, particularly in cardiac surgery. This begs the question of whether hetastarch in a balanced salt (BS) solution (i.e., Hextend®) could avoid these coagulation issues. One must also be aware that HES/NS solution can cause a hyperchloremic metabolic acidosis, as it is not a balanced salt solution (similar to giving excess normal saline). In June 2002 the U.S. Food and Drug Administration (FDA) Blood Products Advisory Committee recommended that HES/BS **(1)** should not have a warning label for bleeding, **(2)** is pharmacologically different from HES/NS, **(3)** is equivalent to 5% albumin, and **(4)** is superior to HES/NS. However, in November 2013 the FDA revised the saftey warning recommending that the use of hydroxyethyl starches **(1)** be avoided in patients with renal dysfunction, at the first sign of renal injury, or severe liver disease, **(2)** requires monitoring of coagulation in patients undergoing open heart surgery associated with cardiopulmonary bypass due to increased risk of bleeding, and **(3)** HES/NS is to be avoided entirely in the perioperative setting in cardiopulmonary bypass patients due to the risk of bleeding.

**Table 41.2 ■ Hespan Versus Hextend**

| | HES/NS |
|---|---|

| | HES/BS (Hextend) | (Hespan/Voluven) |
|---|---|---|
| HES (g/dL) | 60 | 60 |
| Na (mEq/L) | 143 | 154 |
| Cl (mEq/L) | 124 | 154 |
| Lactate (mEq/L) | 28 | — |
| Ca (mEq/L) | 5 | — |
| K (mEq/L) | 4 | — |
| Mg (mEq/L) | 0.9 | — |
| Dextrose (mg/L) | 99 | — |

**Table 41.3 ■ Hetastarch Versus Pentastarch Versus Tetrastarch**

| | Hetastarch | Pentastarch | Tetrastarch |
|---|---|---|---|
| pH | 5.5 | 5 | 4–5.5 |
| Avg. MW | 450,000 | 264,000 | 70,000–80,000 |
| Intravascular half-life | 25.5 hr | 2.5 hr | 12.5 hr |
| Elimination | Renal | Renal | Renal |
| Coagulation effects | Increases PT, PTT, bleeding time | Increases PT, PTT, bleeding time | Increases PT, PTT, bleeding time |
| Liver effects | Temporarily increases amylase, increases indirect bilirubin | Temporarily increases amylase | Temporarily increases amylase |
| Maximum dose | 15–20 mL/kg, max. 1 L | 15–20 mL/kg, max. 1 L | 20–50 mL/kg |

Avg. MW, average molecular weight; PT, prothrombin time; PTT, partial thromboplastin time.

**Table 41.4 ■ Hespan Versus Hextend in Patients Needing Blood**

**Transfusions**

| | HES/NS (N = 25) | HES/BS (N = 31) | P Value |
|---|---|---|---|
| Heart rate, beats/min | 85 | 78 | 0.049 |
| EBL, mL | 2,516 ± 1,856 | 1,560 ± 99 | 0.02 |
| PRBC, mL | 1,516 ± 1,397 | 1,040 ± 639 | |
| FFP, mL | 288 ± 697 | 73 ± 202 | |
| Platelets, mL | 83 ± 205 | 7 ± 38 | |
| Cryoprecipitate, mL | 4 ± 20 | 0 | |

EBL, estimated blood loss; FFP, fresh frozen plasma; HES/BS, Hespan/balanced salt solution; HES/NS, Hespan/normal saline; PRBC, packed red blood cells.

Gan and colleagues studied 120 patients undergoing major elective surgery who received HES/NS or HES/BS intraoperatively. Table 41.4 compares these solutions in patients who required blood transfusions. No statistical differences between groups were found for volume of HES, crystalloid, packed red blood cells (PRBC), fresh frozen plasma (FFP), platelets, or cryoprecipitate infused, or estimated blood loss. However, in the subgroup of patients who received intraoperative blood transfusions, there were significant differences in the mean heart rate and estimated blood loss. In addition, the thromboelastogram (TEG) r-time was measured, and patients who received ≥20 mL/kg of HES/NS had a statistically significant change in r-time from baseline to the end of surgery ($p = 0.01$). Patients who received HES/BS or <20 mL/kg of HES/NS did not have a significant change in r-time.

Bennett-Guerro and colleagues included 200 perioperative (intraoperative plus 24 hours postoperative) coronary artery bypass graft and/or valvular heart surgery patients in a study comparing 5% albumin, HES/NS, and HES/BS administration. No differences between the albumin and HES/BS groups were identified. There was, however, a statistically significant difference between the HES/BS and HES/NS groups regarding the quantity of PRBC and FFP transfused (Table 41.5). Serum creatinine measured 1 week postoperatively was also significantly different between the two groups (Table 41.3).

Gillies and colleagues completed a meta-analysis of recent studies regarding the incidence of postoperative death and kidney injury in surgical patients receiving hetastarch compared to nonstarch solutions. The analysis included 19 studies and 1,567 subjects, and found no statistically significant difference in subjects receiving HES

versus control fluids for resuscitation. In addition, these findings were consistent in subgroup analyses of patients undergoing cardiac and noncardiac surgery. Similar results were shown regarding tetrastarch and AKI by Martin et al. Furthermore, results from Van der Linden and colleagues in a meta-analysis including 59 randomized trials found no difference in mortality, blood loss, use of renal replacement therapy, or peak postoperative serum creatinine. The results also possibly suggested a decrease in the percentage of patients requiring transfusion.

**Table 41.5 ■ Coronary Artery Bypass Graft and/or Valvular Heart Surgery Patients**

| | 5% Albumin | HES/NS | HES/BS |
|---|---|---|---|
| PRBC transfused, U | 2 (0–2) | 4 (2–6)[a] | 2 (0–2) |
| FFP transfused, U | 0 (0–4) | 3 (0–6)[a] | 0 (0–4.5) |
| Platelets transfused, U | 0 (0–6) | 6 (0–9) | 0 (0–6) |
| Preoperative Scr, mg/dL | | 1.0 ± 0.3 | 1.0 ± 0.2 |
| Postoperative Scr, mg/dL | | 1.5 ± 0.7[a] | 0.9 ± 0.2 |

[a]$p < 0.05$ between HES/NS and HES/BS groups. FFP, fresh frozen plasma; HES/BS, Hespan/balanced salt solution; HES/NS, Hespan/normal saline; PRBC, packed red blood cells; Scr, serum creatinine.

In contrast, Hand and colleagues completed a single-center retrospective review of patients undergoing orthotopic liver transplant (OLT). Of 174 patients undergoing OLT, 50 received 5% albumin, 25 received 5% albumin and HES, and 99 received HES only. A statistically significant increase in acute kidney injury (AKI) within 7 days of OLT was found in those patients who received HES. Patients who received HES were up to three times more likely to develop AKI compared to those who received 5% albumin.

According to a study by Skhirtladze and colleagues from the British Journal of Anesthaesia, 240 patients were randomized to receive up to 50 mL/kg 5% albumin, HES tetrastarch, or lactated Ringer's (LR) in the perioperative setting of cardiac surgery. Median cumulative blood loss was not different between groups. However, 62% of those receiving albumin and 64% receiving HES required blood products versus only 35% of those who received Ringer's. The LR group did require more fluid overall. Both colloid solutions interfered with clot formation and clot strength and

caused an increase in serum creatinine.

Finally, Table 41.6 includes several additional studies that support the FDA Blood Product Advisory Committee's recommendations on the use of HES/BS. However, it is still difficult to discern whether the risks associated with resuscitation with HES solutions in the critical care setting are transferable to the general surgical population.

There are several possible adverse reactions one should be aware of when giving hetastarch products: volume overload, pulmonary edema, congestive heart failure, anaphylactic or anaphylactoid reactions (particularly with a corn allergy), hemodilution, nausea/vomiting, peripheral edema, submaxillary and parotid glandular enlargement, mild influenza-like symptoms, headaches, muscle pain, and pruritus. Furthermore, when giving hetastarch in an NaCl solution, direct inhibition of factor VIII, prolongation of activated partial thromboplastin time (aPTT), prothrombin time (PT), clotting and bleeding times, as well as increased risk of hyperchloremic metabolic acidosis have been noted.

**Table 41.6 ■ Comparison of 5% Albumin, HES/NS, and HES/BS**

| | Products Compared | Patient Population | Results |
|---|---|---|---|
| Petroni et al. | HES/BS, 5% albumin/LR | Perioperative cardiac surgery patients (n = 28) | No difference in chest tube output, pre/postoperative Hct, or blood transfusions |
| Gan et al. | HES/BS, 5% albumin/NS | Perioperative GU surgery patients (n = 25) | No significant difference in PT, aPTT, factor VIII, vWF, or platelet function |
| Roche AM | HES/BS, HES/NS, LR | In vitro TEG r-time | 75% dilution of human blood: HES/BS-diluted blood samples had similar r-time as fresh blood; HES/NS-diluted samples failed to |

| | | | |
|---|---|---|---|
| | | | clot. |
| Skhirtladze et al. | Albumin, HES, LR | Perioperative cardiac surgery patients (n = 240) | No difference in chest tube output, increased use of blood products, prolonged CFT and decreased clot strength, increased Scr |

aPTT, activated partial thromboplastin time; CFT, clot formation time; FFP, fresh frozen plasma; GU, genitourinary; Hct, hematocrit; HES/BS, Hespan/balanced salt solution; HES/NS, Hespan/normal saline; PRBC, packed red blood cells; PT, prothrombin time; Scr, serum creatinine; TEG, thromboeslastogram; vWF, von Willebrand factor.

Hetastarch products are available in 500-mL bags. The dosage and rate of administration depend on the clinical situation as well as the dynamics of the patient. According to the manufacturer a recommended maximum of 20 mL/kg or 1,500 mL of the HES product should be used in a 24-hour period, but there are limited data regarding a maximum safe dose.

## TAKE HOME POINTS

- Hetastarch is a colloid that can last intravascularly from 3 to 6 hours.
- Hetastarch comes in a 6% solution of either NaCl (Hespan or HES/NS) or LR (Hextend or HES/BS).
- Hetastarch has relative contraindications in patients with coagulopathies (i.e., liver disease, cardiopulmonary bypass), fluid overload, or renal impairments and may produce hypersensitivity reactions.
- The risk/benefit profile of rescuscitation with hetastarch differs in the critical care patient versus the general surgical patient.
- In June 2002 the FDA Blood Products Advisory Committee recommended that HES/BS (a) should not have a warning label for bleeding, (b) is pharmacologically different from HES/NS, (c) is equivalent to 5% albumin, and (d) is superior to HES/NS. In November 2013 the FDA revised the safety warning recommending that the use of hydroxyethyl starches (a) be avoided in patients with renal dysfunction, at the first sign of renal injury, or severe liver disease, (b) requires monitoring of coagulation in patients undergoing open heart surgery associated with cardiopulmonary bypass due to increased risk of bleeding, and (c) HES/NS is to be avoided entirely in the perioperative setting in cardiopulmonary bypass patients due

to the risk of bleeding.

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42

# Do Not Use CVP to Guide Fluid Resuscitation

Ryan J. Fink, MD

The assessment of volume status, and determining which patients may be hypovolemic and in need of a fluid bolus, is a notoriously difficult task in the clinical setting. Some patients may show obvious signs of hypovolemia, like tachycardia and hypotension, combined with signs of low perfusion to the rest of the body—poor peripheral pulses, cool extremities, low urine output, or altered mental status if awake, to name a few. However, these classic signs and symptoms are not always accurate for hypovolemia, nor easily assessed in the operating room. For example, a patient may be hypotensive and tachycardic due to a large bolus of propofol to induce anesthesia with resultant peripheral vasodilatation, not necessarily because of hypovolemia, per se. Likewise, hypervolemia can be difficult to determine and, at least in terms of excessive fluid administration in the perioperative period, is associated with increased complications.

The main reason to administer a fluid bolus in the perioperative setting is to increase cardiac output (CO), by way of increasing stroke volume (SV) (CO = SV × HR). While directly monitoring CO is not always possible (i.e, via a pulmonary artery catheter [PAC] or transesophageal echocardiography [TEE]), we often accept an increase in blood pressure (BP) as a marker of an increase in CO. If CO (or SV) is increased with a fluid challenge (i.e., an increase in SV of 10% to 15% with a 500 mL bolus of crystalloid over 10 to 15 minutes), the patient is said to be volume responsive. If there is no increase in CO, the patient is volume unresponsive and continued volume administration is not warranted and could even cause adverse effects. Predicting which patients are hypovolemic and will respond to a fluid bolus is of upmost importance, but continues to be challenging.

The central venous pressure (CVP) has been used by clinicians as a measure of intravascular volume status and cardiac “preload” since the 1950s; however, even by the 1970s, this practice was being questioned. The thinking goes: if the CVP is high, intravascular volume is high and patients do not need more cardiac preload, but need vasopressors/inotropes to support their blood pressure or CO; if the CVP is low, cardiac intravascular volume is low and patients need fluid to support their CO/BP. This is based on the faulty assumption that the right-sided CVP can accurately predict

not only RV preload but also LV preload. There are numerous factors that impair the relationship between CVP and both right and left ventricular volumes (Table 42.1), rendering the possibility that CVP is unsuitable for predicting volume status or volume responsiveness.

This has been shown in the literature. In a landmark meta-analysis, Mark et al. showed that, in 24 studies with over 800 patients and in a variety of surgical and medical settings, **there is no relationship between CVP and volume status or predicting volume responsiveness**. Additionally, they showed that the change in CVP with volume administration is similarly unhelpful. Given that these meta-analyses included many different types of patients in the ICU and perioperative period, as well as low heterogeneity, they concluded, "CVP should not be used to make clinical decisions regarding fluid management."

This meta-analysis was updated in 2013 to include more recent studies as well as planned subgroup analyses that separated the operating room from the ICU, and cardiac from noncardiac surgery patients. This meta-analysis included 43 studies with over 1,800 patients, and showed the same results—"CVP is unable to predict fluid responsiveness among a broad range of patients." Indeed, the heterogeneity in this study was zero—all included studies showed the same result—the inability of CVP to predict volume responsiveness. The interaction of technical factors, measurement errors, and physiologic and pathophysiologic effects of surgery and critical illness combine to make the reliability of CVP for predicting fluid responsiveness "barely better than a coin toss." This is in contrast to current recommendations for sepsis, which advocate fluid resuscitation up to a CVP of 8 to 12 mm Hg (higher if mechanically ventilated), mostly based on the landmark study by Rivers et al. However, it must be noted that both the control and treatment groups had the same CVP targets, and in the end, very similar average CVP: 12 mm Hg versus 14 mm Hg, respectively. While statistically significant, this is likely clinically insignificant. In addition, even in healthy volunteers, those whose physiology may most closely mimic that of a healthy patient, CVP is not able to predict volume responsiveness.

**Table 42.1 ■ Factors That Can Distort the Relationship Between CVP and Intracardiac Volumes**

- **Technical factors**
  - Proper assignment of atmospheric pressure as reference ("zeroing")
  - Proper transducer location in relation to external reference point (i.e., 5 cm below the sternal angle)

  - Changes in patient positioning
- **Interpretation factors**
  - Timing of the measurement in relation to the respiratory cycle (i.e., end-expiration)
  - Measurement at the onset of the c-wave (i.e., after atrial contraction, before the TV closes)
- **Cardiac factors**
  - Changes in RV compliance (i.e., heart failure, myocardial infarction)
  - Changes in LV compliance (i.e., diastolic dysfunction, sepsis, myocardial infarcation)
  - Valvular disease (especially tricuspid regurgitation and stenosis)
- **Changes in intrathoracic pressure**
  - Positive-pressure ventilation
  - PEEP
  - Spontaneous ventilation, forced expiration
- **Pulmonary arterial hypertension**
- **Changes in venous tone** (i.e., hyperadrenergic states)

CVP, central venous pressure; LV, left ventricle; PEEP, positive end-expiratory pressure; RV, right ventricle; TV, tricuspid valve.

This does not mean that placing a central line or monitoring the CVP waveform does not have some utility. Central lines are often needed for patients with otherwise inadequate intravenous access, those that require large volume resuscitation, infusion of various medications that are more safely given into a large central vein, or if the patient requires a PAC or transvenous pacing. In addition, the CVP waveform may alert the clinician to arrhythmias (i.e., in atrial fibrillation the a-wave disappears), valve problems (i.e., a tall c-v wave with tricuspid regurgitation), or acute right heart failure.

If the CVP cannot, or should not, be used to predict volume responsiveness or the volume status of a patient—and heart rate, blood pressure, and urine output are not much better—what can we use? The PAC has fallen out of favor for multiple reasons, including a similar lack of relationship between pulmonary capillary wedge pressure (PCWP) and volume responsiveness. TEE is almost exclusively used in the cardiac surgery population, although smaller and more automated probes have been developed.

The dynamic changes in hemodynamic variables (such as pulse pressure, systolic pressure, and stroke volume) appear to hold the most promise for predicting volume responsiveness. A full discussion of the physiology underlying, and the monitors of, these changes are beyond the scope of this chapter. However, they all rely on the variation of intracardiac loading conditions during positive-pressure ventilation. The

variation of systolic pressure and pulse pressure can be measured manually on a monitor in patients with arterial catheters, as well as other manual or automated methods based on the same principles (Table 42.2). If a patient is breathing spontaneously or has an arrhythmia that precludes the use of pulse pressure variation or similar monitors, the passive leg raise test has been shown to predict volume responsiveness with much more accuracy than the CVP.

With improvements in the monitoring for, and prediction of, volume responsiveness, another question arises: just because a patient is fluid responsive, do they need fluid? If blood pressure and cardiac output are adequate, but the patient has a high likelihood of increasing these in response to a fluid bolus based on pulse pressure variation, for example, should fluid be given? The answer to this question remains to be answered. However, if a patient is hypotensive, and a dynamic indicator of fluid responsiveness (as listed in Table 42.2) suggests a positive response, it is much more likely to be true than if the decision is based on the CVP.

**Table 42.2 ■ Methods Available for Noninvasive Stroke Volume and Cardiac Output Measurements, and Their Variation With Positive-Pressure Ventilation**

- Pulse pressure variation, systolic pressure variation
- Esophageal Doppler
- Pulse contour analysis
- Bioimpedance and bioreactance
- Plethysmographic waveform analysis
  - Pleth variability index; Masimo Corporation, Irvine, CA
- Inferior vena cava diameter (ultrasound)

## TAKE HOME POINTS

- The CVP does not perform well in predicting fluid responsiveness.
- The CVP should probably not be used to guide fluid management in the perioperative period.
- Systolic pressure variation, pulse pressure variation, or the multiple automated monitors available to assess these dynamic variables perform much better at predicting whether a patient will increase his or her stroke volume and cardiac output with a fluid challenge.

- If a patient is spontaneously breathing, consider the passive leg raise test, which also predicts fluid responsiveness much more accurately than the CVP.

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## SECTION IV

# TRANSFUSION MEDICINE

43

# Introduction

Melissa R. George, DO

Throughout human history, blood has carried an air of mysticism that persists despite centuries of investigation into its physiology and properties. Blood transfusion is one of the most common procedures in American hospitals, yet is one of the most misunderstood. We believe this is because blood and blood products are truly complex therapeutic modalities—they are volume-expanding fluids as well as incredibly powerful, but sometimes dangerous, vehicles for the remediation of critical and often life-threatening physiologic injuries.

Australian transfusion medicine specialist Dr. Robert Beal was famously quoted as saying "Blood transfusion is like marriage: it should not be entered upon lightly, unadvisedly or wantonly or more often than is absolutely necessary." While the blood supply is safer than ever, two erroneous extremes in thinking about transfusion persist. One is that because blood is "natural"; it is without risk. The other is an abject fear of transfusion based on the HIV crisis of the 1980s. Reality lies somewhere in between.

While most academic centers and some large community hospitals have specialists trained in Transfusion Medicine, the majority of transfusion decisions are made on the frontline by clinicians from a spectrum of specialties with varying degrees of formal training in transfusion practice. Recent studies have demonstrated major transfusion medicine knowledge deficits in trainees across a wide range of specialties, suggesting that more "on the job" education is needed.

The American Society of Anesthesiologists noted in a press release several years ago that there were about 30 million units of blood components transfused in 2011, with about half of all units being given in the operating room.* As such, anesthesiologists are key partners with Transfusion Medicine specialists in implementing patient blood management and safer transfusion practices. The following chapters offer a primer on common blood components, basic blood bank ordering, and special considerations in transfusion practice.

We hope that these chapters will demystify basic elements of Transfusion Medicine critical to anesthesiology practice. We also welcome questions, phone calls, and consultations at any time to discuss the clinical situations, the specific transfusion

products needed, and even the timing of the planned transfusions. We believe that a close collaborative relationship between Transfusion Medicine and the perioperative services results in the safest transfusion for the patient.

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*https://www.asahq.org/about-asa/newsroom/news-releases/2014/12/top-blood-transfusion-related-complication-more-common-than-previously-reported?page=6

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# Know What Screening Tests Are Performed on Volunteer Donor Blood

Melissa R. George, DO and Andrew M. Gross, MD

Donated blood is subjected to a rigorous series of tests before it is deemed safe for transfusion. The list of tests performed by blood product suppliers seems ever expanding, and this has resulted in an overall safer blood supply and fewer transfusion-associated risks. Blood testing consists of screening for infectious disease as well as ABO screening, Rh screening, and screening for red cell antibodies.

## Queries and Questionnaire

Infectious disease screening is accomplished two ways. An initial level of screening is by self-report of previous diseases and living or travel situations. Since March 2005, all blood donors in the United States must complete a lengthy survey called the Donor History Questionnaire. For example, donors are asked if they have had oral surgery in the last 3 days (to eliminate the possibility of transient bacteremia of mouth pathogens) or have ever had certain bloodborne infections such as malaria or babesiosis (both intracellular erythrocyte parasites). They are asked about high-risk behaviors such as sexual contacts (male to male sexual contact, receiving payment for sex, sexual contact with a high-risk partner, sexually transmitted disease diagnosis), IV drug use, and incarceration to assess for risk of bloodborne/sexually transmissible disease. They are also queried about residence in Europe during the interval that may increase the epidemiologic risk for bovine spongiform encephalopathy. Affirmative answers on the test can disqualify the donor temporarily or permanently.

## Serum Screening

Serum tests for infectious disease entities include HIV-1 and -2, hepatitis C (HCV), hepatitis B (HBV), human T-lymphocyte virus (HTLV)-I and -II, West Nile virus, and Treponema pallidum (syphilis). Alanine aminotransferase is also tested as a laboratory marker of infectious disease. All viruses are initially tested for by enzyme-linked immunoassay (ELISA, EIA) or chemiluminescent immunoassay (ChLIA). An initial

positive result is then rechecked in two separate ELISA tests, and if one of those two subsequent tests is also positive, the blood is discarded. Only if both are negative is the blood taken out of special quarantine and subjected to further testing. A new method of testing blood was started in 1999. Nucleic acid testing (NAT) is used to screen blood for the presence of HIV, HCV, and, as of 2003, West Nile virus. NAT is done by polymerase chain reaction (PCR) or transcription-mediated amplification (TMA). As both of these are fairly expensive tests, most commonly NAT is done on a mini pool sampling. This involves pooling multiple donations, and if an infection is present, then all of the individual donations in the pool are tested. This supersensitive assay is responsible for detecting HIV an average of 11 days earlier than other forms of testing, and in concert with ELISA and Western blot tests for anti-HIV antibodies, has decreased the risk of transfusion-related infection to 1 in 2 million in the United States, 1 in 5 million in Germany, and 1 in 10 million in Canada. HCV infection has been dramatically reduced using NAT, from 1 in 100,000 in 1996 to 1 in 2 million in the United States in 2005. NAT results in a decrease from an average of a 70-day window for undetectable infection using ELISA screening for HCV antibodies to an 8- to 10-day window of undetectable infection.

Blood infected with HBV is screened for by hepatitis B surface antigen and core antigen testing. The latency period of about 60 days results in a higher amount of undetected virus in the donor pool and thus HBV infection risk remains the highest among the diseases tested for—estimates vary from 1 in 60,000 to 1 in 270,000. HTLV-I and -II are screened for by ELISA and confirmed by Western blot or PCR. The resulting infection rate is estimated at 1 in 2 million for HTLV. Syphilis is also screened for by a number of serologic assays varying from lab to lab using highly sensitive specific antigens for T. pallidum. While transfusion-transmitted syphilis has not occurred in the United States for many years, testing for T. pallidum mainly serves as a marker of high-risk behavior that could increase the risk of HIV, HBV and HCV. Finally, cytomegalovirus (CMV) is screened for only in a select number of cases, because of the need for CMV-negative blood for transplant recipients and the immunosuppressed population, especially HIV-infected individuals. In 2010, the FDA mandated antibody testing against Trypanosoma cruzi (Chagas Disease) via testing for antibodies via EIA, and/or ChILA. In 2016, Zika virus NAT was implemented in response to the spread of Zika in the Caribbean and Southern United States and its devastating potential association with microcephaly and birth defects if acquired in utero.

## Platelets

Platelets, which are stored at room temperature, carry additional risk of bacterial

contamination. Therefore, testing to detect possible bacterial contamination of platelet units is mandated. This testing can be accomplished via culture, Pan Genera Detection (PGD) test (which detects antigens—lipoteichoic acids on gram-positive bacteria and lipopolysaccharides on gram-negative bacteria), or a test that uses oxygen concentration inside a small pouch as a measure of oxygen consumption by bacteria. Platelets also have a limited shelf life for this very reason. Red cells are somewhat protected from the growth of most bacteria, as most do not survive refrigeration. However, psychrophilic bacteria such as Yersinia enterocolitica can survive refrigeration and reach infective levels. No screening currently exists for this rare contaminant.

## Blood Type and Antigen Testing

In addition to infectious agents, blood type testing is still of critical importance, and all blood donations are screened for ABO type using anti-A and anti-B antibodies. Each unit is also tested for the presence of a D antigen. Those who have the D antigen are said to be Rh-positive, and those without, Rh-negative. Every unit that types as D-negative is tested again via the extra sensitive indirect antihuman globulin test to rule out the possibility of "weak" or "partial" D to be absolutely sure that the unit is Rh-negative before transfusion to an Rh-negative recipient. Blood types and Rh type are rechecked in individual hospital blood banks before dispensing units for transfusion, as the result of a mislabeled or improperly tested unit could be catastrophic or even fatal. Some but not all donated blood is subsequently screened for red cell antigens. These antigens include the remainder of the Rh system in addition to the D antigen and the more minor groups (e.g., Duffy, Kell, Big E, Kidd). Special units that are negative for all of these antigens are stored for transfusion to people who have preformed antibodies to these groups. Cross-matching is done in the blood bank at individual hospitals to determine compatibility of the packed red cell product with the transfusion recipient. Donated blood is itself screened for antibodies to the minor blood groups by exposing it to an antibody screen consisting of control red cells that have known antigens present on their surface. This antibody screen rules out the majority of clinically significant antibodies. The components that have preformed antibodies cannot be given to a recipient with the corresponding antigen, as major complications can arise.

## Understanding and Managing the Patient's Anxiety

Blood transfusions are a crucial part of practicing anesthesiology. Many critically ill patients' lives will depend on receiving transfusions that are safe and properly administered. In order for an informed decision to be made by both physician and patient, it is important to understand the risks of blood administration. Transfusions are still a source of anxiety for patients, and knowing how to alleviate that fear is of the

utmost importance. Most anxiety surrounding blood transfusion stems from patients' fears of contracting an infectious disease, and although the risk is low, it is not zero. Of understandable concern to patients is the risk of acquiring a disease from an "emerging" condition such as Lyme, ehrlichiosis, or babesiosis; all conditions that are well established in the United States. These and other conditions with known or probable blood transmission can be debilitating or fatal if acquired and are not tested for in the blood supply in the United States. A test for Babesia is available and is seeing some implementation in endemic areas, although its use is not yet mandated. When discussing the risks of acquiring these diseases (or yet-unknown diseases; thousands of patients died from AIDS acquired through blood transfusions), it is incumbent to tell patients that self-report measures have never been proven to be fail-safe screening procedures for preventing transmission of bloodborne pathogens. It is also important to reassure patients that the blood supply is safer than ever thanks to the advent of highly sensitive testing.

## TAKE HOME POINTS

- Screening of volunteer donor blood starts with the Donor History Questionnaire—this is strictly a "self-report" instrument that attempts to indirectly screen for such bloodborne diseases as malaria and babesiosis. For a true positive diagnosis, both these diseases require a peripheral blood smear analysis, which is not performed on donated blood. In Lyme-endemic areas, such as Connecticut, it has been determined that a certain percentage of volunteers presenting for blood donation are actually asymptomatic carriers of the babesia parasite. Transfusion-related transmission of the disease has been reported.
- The first level of serologic testing is by ELISA—this is intended to screen against viral and spirochetal organisms.
- NAT is usually done on pooled samples and has increased the sensitivity of the serologic testing process.
- The blood supply has increased in safety in recent years, but of course is not completely safe, and the risks should not be minimized or "glossed over" in discussions with the patient. A good approach is to discuss the relative risks of transfusion versus significant perioperative events linked to anemia, such as retinal ischemia and visual loss. Don't guess when patients ask you about screening for a particular agent that they have heard about or read about and you don't know the answer. Tell them that you don't know, the screening protocols are continually updated, and offer to place a call to the Transfusion Medicine service to check. They are always ready and happy to answer questions.

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# Red Blood Cell Primer

Melissa R. George, DO

Packed red blood cells (pRBCs) are the most commonly transfused blood product. Close to 12 million units of pRBCs were administered in 2015 in the United States alone. Unfortunately, transfusion practice varies greatly and red blood cell (RBC) transfusion is often initiated as a matter of clinician habit rather than as an objective response to recognized parameters. The only proper uses of RBC transfusion are to treat symptomatic anemia or active bleeding and improve oxygen-carrying capacity/delivery to tissues. **RBCs should never be used solely as a volume expander**. The goal of pRBC transfusion should always be a balance of optimizing clinical outcomes while avoiding unnecessary risks of infections, and noninfectious transfusion complications. With greater focus on patient blood management, both from a patient safety and cost-conscious perspective, educated decisions must be made regarding pRBC transfusion. Recent literature has attempted to shed light on best practices and offer practical guidelines on appropriate RBC transfusion. This chapter offers a brief primer on the proper use of RBC products and a practical overview of associated risks.

The main RBC product is pRBC which is prepared from a whole blood donation from an individual donor. pRBCs can also be collected by apheresis donation in which RBCs are selectively removed via a centrifugation process from a blood donor with return of platelets and plasma back to the donor. pRBCs have a hematocrit of about 55% to 65% and a volume of 250 to 300 mL depending on the volume of whole blood or apheresis pRBC initially collected. Most pRBC units are stored in an additive solution that allows for a storage life of 42 days. One unit of whole blood or packed red cells is expected to raise the hemoglobin by 1 g/dL and the hematocrit by 3% and in an average adult. Weight-based dosing of 10 to 15 mL/kg in a child is expected to raise the hemoglobin by 2 to 3 g/dL and the hematocrit by about 6%. With the exception of isotonic saline, no other solutions or medications should ever be infused through the same tubing as or added to a pRBC transfusion. Solutions that are hyper or hypotonic could potentially cause hemolysis and should be avoided in close proximity to a transfusion. Packed RBCs should also be infused through a blood administration filter of 170 to 260 microns to remove any particulate matter or clumped cells that may be

present in the unit.

pRBCs stored in a plastic bag acquire a phenomenon known as the “red cell storage lesion.” pRBCs are stored at 1 to 6°C, which slows metabolic processes and has the additional benefit of being an inhospitable environment for most bacteria. Additive storage solutions provide an energy source (adenine), anticoagulant and other preservatives to keep the cells viable and as close to physiologic as possible for up to a 42-day shelf life. During storage, RBCs due incur damage to the sodium-potassium pump, which results in the gradual release of intracellular potassium into the supernatant. The potassium concentration within the supernatant increases linearly from approximately 2 to 45 mEq/L over 42 days. The influx of this relatively small amount of potassium is generally well tolerated in a recipient with adequate renal function; however, it can be problematic for hyperkalemic patients with renal failure and also for neonates sensitive to electrolyte shifts. Additionally, the morphology of RBCs changes from that of a biconcave disk which is optimal for oxygen carrying to a relatively spherical echinocyte with projections all around the surface as a result of crenation. This morphologic change is less optimal for oxygen carrying and delivery. Red cells also lose 2,3-DPG during storage. Upon entry into the circulation of a transfusion recipient, many of these morphologic and physiologic changes induced by storage are rapidly corrected.

pRBCs can be modified further based on clinical need. These modifications include:

## **Washing** (Please see Chapter 53 on Washed Products for More Detail)

- to remove potassium in the supernatant before transfusion to a patient extremely susceptible to hyperkalemia,
- to remove IgA from residual plasma for transfusion to an IgA-deficient patient with anti-IgA
- to remove protein allergens in residual plasma in patients who have had repeated, severe allergic reactions to blood transfusion, refractory to antihistamine and steroid treatment

As discussed in Chapter 53 (Washed Products), washing should be used judiciously as it is a time consuming and labor intensive process that reduces the number of RBCs in the unit and shortens the shelf life to 24 hours.

## Irradiation

- to prevent transfusion-associated graft-versus-host disease (TA-GVHD) by killing lymphocytes in the product. Used for certain extremely immune-compromised individuals such as patients with hematologic malignancies, sarcomas, and those who are candidates for bone marrow transplantation.

Irradiation must be performed at centers with an approved irradiator and also shortens the shelf life of the product to 28 days or the original outdate, whichever is sooner.

## Leukoreduction

- to remove the majority of white blood cells in a pRBC unit, thus reducing the risk of CMV transmission, febrile nonhemolytic transfusion reactions and human leukocyte antigen (HLA) alloimmunization.

Of note, whole blood is rarely used anymore, as component therapy offers more targeted therapy toward a pathophysiologic aberration of blood constituents. Blood components offer greater flexibility, especially in terms of ABO compatibility. For example, while group O blood is the universal RBC donor, the group O plasma contained in whole blood could cause hemolysis in group A or B patients.

## Infectious Complications of pRBCs

In general, pRBCs carry the same inherent infectious disease risks as other blood products. Thanks to the implementation of highly sensitive nucleic acid testing for many viral agents, window periods have decreased dramatically and the general risk of acquiring an infectious disease from a blood transfusion is quite low as listed below:

- HIV—1 in 2 million transfusions
- HBV—1 in 200,000 transfusions
- HCV—1 in 2 million transfusions

Blood donations are also screened for HTLV 1/2, West Nile Virus, Zika Virus, Chagas disease, and syphilis. Other transfusion transmissible infections include Chikungunya Virus, Dengue Virus, and Babesiosis; however, testing for these infectious agents is not performed on blood donors.

## **Noninfectious Complications** (Other Than Transfusion Reactions)

In addition to ABO/Rh, RBCs carry hundreds of other antigens on their surface. Exposure to antigens on foreign RBCs can lead to alloimmunization or the development of antibodies that can cause hemolytic disease of the newborn and increase the difficulty of finding pRBC for future transfusions. This is especially significant in multiply transfused patients such as those with sickle cell disease. Multiple transfusions can also lead to iron overload as a single unit of blood contains about 250 mg of iron. The human body only needs about 1 mg of iron to replace physiologic losses each day. Iron overload from frequent transfusions can lead to liver and cardiac damage.

While transfusions can be life-saving, there is a growing consensus in the medical literature that a restrictive transfusion strategy results in lower mortality than does a liberal transfusion strategy. A landmark study was conducted in 2012 by Carson JL et al. proposing practical guidelines on red cell transfusion with input from the AABB (formerly American Association of Blood Banks). This study was a systematic review of randomized clinical trials evaluating transfusion thresholds from 1950 to 2011. The study reviewed the proportion of patients receiving any pRBC transfusion, and the number of units used. Clinical consequences of restrictive transfusion strategies were carefully examined in the context of mortality, cardiopulmonary events, alterations of hemostasis, organ failure, infection, and length of hospital stay among other parameters. This study, which included thousands of pRBC recipients across a variety of clinical conditions, led to the recommendations of a restrictive transfusion strategy (7 to 8 g/dL) in stable, hospitalized patients with or without cardiovascular disease; consideration of transfusion of patients with symptomatic anemia or hemoglobin level ≤8 g/dL; and use of clinical judgment in hemodynamically stable patients with acute coronary syndrome. There is a lack of data regarding transfusion thresholds in patients with acute coronary syndrome and therefore, there are no evidence-based recommendations.

In general, while pRBC transfusion can be life-saving, there is increased focus on blood product stewardship and outcomes analysis of transfusion practice. The Food and Drug Administration views blood both as a biologic and a drug. Just as one would

never prescribe a medication without thorough consideration of anticipated therapeutic effect, potential side effects, comorbidities, and the benefit to risk assessment balancing test, transfusion decisions should also be made with the same scrutiny.

## TAKE HOME POINTS

- The only appropriate use of pRBCs is the treatment of symptomatic anemia or active bleeding to improve oxygen-carrying capacity.
- Modifications of pRBCs include cell washing, irradiation, and leukoreduction.
- Transfusion decisions should be based on clinical symptoms as well as laboratory evidence.
- pRBC transfusion carries infectious (rare) and noninfectious risks such as transfusion reactions, alloimmunization, and iron overload.
- Current evidence-based guidance recommends:
  - a restrictive transfusion strategy (7 to 8 g/dL) in stable, hospitalized patients with or without cardiovascular disease
  - consideration of transfusion in patients with symptomatic anemia or hemoglobin level ≤8 g/dL
  - use of clinical judgment in hemodynamically stable patients with acute coronary syndrome.

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# Type and Screen or Type and Cross-Match?

Diana S. DeAndrade, MD and Michael L. Boisen, MD

Blood transfusions are among the most common in-hospital procedures performed, with an estimated 30 million units of blood products administered each year in the United States.* Given that a significant proportion of blood products are administered in the perioperative setting, anesthesiologists and nurse anesthetists should be familiar with appropriate blood ordering practices in order to improve efficiency, reduce unnecessary costs, and optimize patient care. At the heart of perioperative blood ordering is the decision to obtain a type and screen, a type and cross-match, or no pretransfusion testing at all.

## Type and Screen

The type and screen (T/S) consists of two separate tests: the "type" determines which ABO and RhD antigens are expressed on the patient's red blood cells (RBCs), and the "screen" checks the patient's serum for the presence of unexpected non-ABO antibodies.

ABO blood type is determined using both a forward and reverse process. In forward typing, patient RBCs are mixed with commercially available anti-A and anti-B antibodies that will react with A or B antigens if present on the RBC surface and cause agglutination. In reverse typing, patient plasma is added to commercially available group A and B RBCs, again looking for agglutination. RhD type is determined in a manner similar to the forward type by mixing anti-RhD antibodies with patient RBCs. ABO and Rh typing can be completed in 10 to 15 minutes.

The antibody screen is a test for unexpected (non-ABO) antibodies. It involves incubating patient plasma with a reference panel of RBCs that express virtually all clinically significant non-ABO antigens (antigens capable of causing hemolysis) and observing for agglutination or hemolysis. Depending on the technique used, the antibody screen requires an additional 30 to 45 minutes after ABO/Rh typing. A positive screen indicates the presence of at least one unexpected antibody (alloantibody) produced in response to previous pregnancies or transfusions (alloimmunization).

A positive antibody screen occurs in approximately 5% of the patients and reflexively triggers additional testing to identify the antibody specificity—testing that may be time consuming. Once antibodies are identified, locating compatible RBCs can also be time consuming, and once located, a serologic cross-match is required to verify compatibility (see below). For this reason, although it is not necessarily automatic, some blood banks may convert a positive T/S to a type and cross-match (T/C) for 1 to 2 units if the patient is scheduled for surgery in an effort to prevent delays.

## Cross-Matching

The cross-match is a compatibility check between recipient and donor RBCs to be transfused, and also reserves donor RBC units for transfusion. Historically, in vitro cross-matching was performed on every unit intended for transfusion using a serologic technique except in emergencies. Serologic cross-matching involves mixing recipient plasma or serum with donor RBCs and requires an additional 15 to 45 minutes to complete.

Improvements in methodology led to recognition that patients with a negative antibody screen and no prior history of RBC antibodies do not require a complete cross-match, as their risk of a clinically significant missed antibody is 0.005%. In such patients, a computerized analysis of compatibility (the "electronic cross-match") can be used, provided the patient has two separately drawn ABO/Rh types on record. As physical mixing of samples is not necessary, blood banks that perform computerized cross-matching can issue compatible RBC units for eligible patients in less than 5 minutes. Since approximately 95% of transfused patients have a negative antibody screen, the vast majority of patients may be eligible for computerized cross-matching.

## Optimizing Perioperative Blood Ordering

Overordering of blood products drives up laboratory, personnel, and inventory costs—costs which are transmitted to both hospital and patient. Unnecessary cross-matching increases the blood bank inventory that must be maintained, as reserved units are unavailable to be issued to other patients, typically for 3 days, and may outdate before use. On the other hand, incomplete pretransfusion testing on the day of surgery can lead to surgical delays and cancellations. Therefore, blood ordering practices should ideally be matched to the probability of transfusion based on objective patient- and procedure-specific data.

In an early effort to standardize blood ordering, Friedman developed the maximum surgical blood ordering schedule (MSBOS) in the 1970s which listed various surgical procedures and the corresponding recommended blood orders. This approach has been shown to reduce unnecessary cross-matching and improve efficiency. Since its

introduction, many institutions have refined the MSBOS to be based on local blood utilization data to more accurately predict transfusion needs.

Despite its utility, the MSBOS recommends cross-matching for twice the median number of units transfused for a given surgical procedure, which may be excessive in many cases. Palmer et al. reported that only 16% of patients who underwent preoperative T/C per MSBOS recommendations actually received an intraoperative transfusion. In light of the rapidity with which compatible units can be issued using computerized cross-matching, a reasonable approach is to defer cross-matching in eligible patients until the RBCs are actually needed. Lin et al. demonstrated a significant reduction in unnecessary cross-matching using this approach, with a minimal increase in turnaround time (14 minutes vs. 13 minutes). Some centers have extended computerized cross-matching to electronic remote blood issue systems located in clinical units—automated, networked blood storage, labeling and dispensing systems that decrease blood issue times to 1 to 2 minutes and further decrease unnecessary cross-matching.

Even a sophisticated, evidence-based MSBOS represents guidelines for blood ordering, guidelines which may need to be modified based on the clinical situation. Patient- and surgery-specific variables such as preoperative hematocrit, patient comorbidities, lowest tolerable hematocrit, rate of anticipated bleeding, and medications such as antiplatelet or antithrombotic agents may need to be taken into account.

Recall that computer cross-matching cannot be used for patients with a positive antibody screen or patients without a second ABO/Rh type on file (a "check" sample). For this reason, elective surgical patients who require T/S should ideally have preadmission testing. Patients who have not been pregnant or transfused in the preceding 90 days can have a T/S obtained up to 1 month before surgery at many institutions. Patients who have been pregnant or transfused within the previous 90 days are at higher risk of having formed antibodies, and therefore their time window for a valid T/S is limited to 72 hours. Note that in order for a preadmission T/S to remain valid on the day of surgery, patients must maintain their unique identifier issued by the blood bank at the time the sample is acquired (often a bracelet). When possible, obtaining the T/S prior to the day of surgery improves operating room efficiency by providing ample time to screen for alloantibodies and obtain compatible RBCs thus avoiding surgical delays or cancellations. An additional opportunity at this time exists for detection and optimization of preoperative anemia prior to elective surgery.

In summary, a thorough understanding of pretransfusion testing and evidence-based blood ordering allows the anesthesia team to provide maximally safe and efficient patient care.

## TAKE HOME POINTS

- Remember that the transfusion of blood is not just "giving fluids." It's really best conceptualized as an active intervention or procedure—and a costly and invasive one at the minimum.
- The type and screen identifies the ABO/RhD blood group and screens for non-ABO RBC antibodies. This test generally requires 45 to 60 minutes for completion.
  - The type and cross-match ensures compatibility between a specific donor product and the recipient's plasma, and may be done electronically in less than 5 minutes or by physically mixing the two (10 to 45 minutes).
  - Only those recipients with at least two concordant ABO/RhD types on file, a current negative antibody screen, and no prior record of non-ABO antierythrocyte antibodies are eligible for electronic cross-matching.
  - Procurement of compatible RBCs can take hours to days depending on the prevalence of the antigen to which the recipient has an alloantibody in the general population.
  - The MSBOS is a helpful tool for reducing unnecessary preoperative blood orders, but should ideally be institution-specific and used in conjunction with patient-specific variables.
  - Pretransfusion testing prior to the day of surgery helps reduce surgical delays and cancellations by facilitating the timely acquisition of compatible blood products.
  - In most cases, a preoperative type and screen is sufficient and cross-matching can be deferred until RBCs are needed.

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# Special Circumstances: Patients With Antibodies

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While clinicians typically think about ABO and Rh type for transfusion purposes, there are actually close to 600 blood group cell antigens. The majority of these blood groups are named after the patients found to have the antigen or to have formed the first identified antibody against the antigen. The incidence of a patient having a non-A, or B antibody is approximately 0.2% to 2% in the general population, while such antibodies are estimated to occur in 14% to 50% of chronically transfused patients with sickle cell anemia or thalassemia. Blood group antibodies increase the difficulty of finding compatible units. We are unable to predict which patients will form antibodies against red blood cell antigens. Some patients can be multiply transfused and never form a single antibody, others may form multiple antibodies after limited exposure. For patients with red cell antibodies, the likelihood of finding a compatible unit of blood (in other words, the likelihood that any one unit is compatible) is calculated as below:

First, identify the percentage of the donor population (assuming a predominantly Caucasian donor pool) that is negative for the antigen to which the patient has the antibody:

Antigen negative = 1 − antigen prevalence

Then, take the likelihood of negativity for each antigen and multiply.
For example, in a patient with anti-K and anti-C antibodies:

Likelihood of K (Kell) negativity = 1 − 0.9 = 0.91
Likelihood of C negativity = 1 − 0.68 = 0.32
Likelihood of K and C negativity = 0.91 × 0.32 = 0.29, or 29% chance of not finding this antigen combination in the donor pool.

Suppose this patient needs multiple units of blood for surgery. You would need to take the number of units needed, divided by the incidence of antigen-negative blood

using the formula below:

$$\text{Antigen negative} = 1 - \text{antigen prevalence}$$

As the number of antibodies increases, the complexity of this calculation increases. The incidences of antigen-negative blood in decimal format are multiplied together in the denominator. This calculation provides an idea of how many pRBC units would need to be screened to find a given number of compatible units. Suppose the patient with anti-K and anti-C needs six units of pRBC:

6 units/(0.29) = approximately 21 units of blood would need to be screened to find 6 compatible units.

Blood suppliers have increasingly incorporated molecular data into antigen analysis to be able to have antigen types available on a wider number of units than traditional serology will allow.

Some patients have special needs that require the use of blood from rare blood donors. A donor is labeled as a rare blood donor if they meet one of the following criteria:

) Being negative for a high-prevalence antigen. High-prevalence antigens are found on the majority of individuals' red blood cells. The likelihood of being negative for a high-prevalence antigen is approximately 1 in 1,000 persons.

) Being negative for multiple common antigens. Some patients form multiple antibodies against red blood cell antigens. These individuals need blood that is negative for multiple antigens, which drops the likelihood of finding compatible units dramatically.

) IgA deficiency (<0.05 mg/dL IgA tested on two separate occasions). Patients who are IgA deficient and have formed anti-IgA antibodies are at risk of severe anaphylactic reactions. These individuals need IgA-deficient plasma products. While red blood cells and platelets can be washed, plasma and cryoprecipitate cannot and products must be obtained from deficient donors (See Chapter 53 for more information).

The American Rare Donor Registry is a database of over 50,000 active donors maintained by the American Red Cross based in Philadelphia, PA. Requests are entered into the database and matched with donors believed to be compatible. Products may be liquid or frozen. Frozen products pose an additional challenge because they require extensive processing before shipping and are not available quickly. If compatible units are not available, other options such as recruitment of known rare donors, testing family members, autologous collection or beginning an international search may be necessary. Rare units may take up to 72 hours to obtain. Despite a plethora of phenotypes being

available in the rare donor registry, some extremely rare phenotypes have not been identified in the donor population and matched blood may not be available for patients with these exceedingly rare antibodies.

Besides availability of rare units, there are a number of other logistical challenges associated with their use. Some rare units are frozen to enable a shelf life of 10 years and in some cases, longer. Red cells are frozen in glycerol to protect them from lysis during the freezing process. Frozen units must be thawed and deglycerolized before use. This process shortens the shelf life of these units to 24 hours as the process must occur in an open system which increases the risk of bacterial contamination. If these units are not used, a particularly precious resource is wasted. Frozen units also have a much higher incidence of storage bag breakage, which also wastes a precious resource. Additional costs are associated with obtaining blood from the rare donor registry. On average, a unit of pRBC costs a hospital about $220 based on 2013 data. A unit of pRBC from the Rare Donor Registry may have additional fees averaging about $1,000 per unit. Blood obtained from other countries is even more costly with additional fees ranging from $2,000 to $2,800 per unit. A final caveat is that units frozen for extended periods of time might not have had the same rigorous infectious disease testing performed as the testing may not have been available at the time the unit was frozen. Units imported from other countries are considered "untested" by US regulatory agencies. So, there is some risk from an infectious disease standpoint in transfusing such units.

While we have extensively discussed the logistics of obtaining rare blood, there are instances in which fully antigen-negative, compatible blood cannot be obtained. There is limited guidance on expected outcomes other than knowing that this is a calculated risk of hemolysis. In general, the risk of a non-ABO–mediated hemolytic transfusion reaction is about 0.1% of emergently transfused pRBC. The transfusion medicine community has largely been pulling away from directed donation (from a patient's family members) or autologous donation (from the patient); extremely rare phenotypes are exceptions to this rule. Patients with rare phenotypes could consider banking their own blood for future need.

When approaching a surgical procedure, it is requisite that the anesthesiologist performs an assessment of the patient's risk of bleeding/potential need for RBC transfusion and thus the appropriateness of a type and screen (T/S), a type and cross-match (T/C), or to forego sending a sample to the blood bank. It is also important for the anesthesiologist to be mindful that a T/S order can typically be performed within 1 hour and involves determining the patient's ABO group, RhD type, and screening the patient for clinically significant antibodies.

When antibodies are detected, the additional testing required to identify the

antibodies and locate appropriate antigen-negative RBC units may take hours or even days to complete. In an effort to aid the anesthesiologist in determining the appropriateness of T/S, T/C Friedman et al. in the early 1970s implemented a maximum surgical blood ordering schedule (MSBOS) to standardize blood product ordering according to surgical procedure. Modernization of the schedule was performed by Frank et al. in 2013 after noting advancements in surgical techniques and technology (robotic, laparoscopic, etc.) subsequent to the schedule's original publication. If a T/S is ordered, anesthesiologists must recognize that up to 2% of all patients will have an antibody screen. A 2003 study from the College of American Pathologists (CAP) showed that of the 2% of patients with a positive screen, 33% required special and prolonged efforts to obtain blood. The recommendations of the probe included open communication between blood banks and the anesthesiologists, and policies regarding the timing and completion of T/S samples which is beyond the scope of this chapter. If an alloantibody is detected, the anesthesiologist must be aware that there is a significant risk that compatible RBCs may not be available when needed. Anesthesiologists (and surgeons) need to ensure patient samples are obtained and tested prior to start of the case by placing blood orders in a timely fashion and communicating directly with the blood bank if the patient has a positive antibody screen.

## TAKE HOME POINTS

- The incidence of non-ABO antibodies is approximately 0.2% to 2% in the general population.
- Blood group antibodies increase the difficulty of finding compatible pRBC units.
- Patients with an antibody against a high-prevalence red cell antigen, multiple antibodies, or IgA deficiency with anti-IgA may require blood products from the American Rare Donor Registry.
- Obtaining rare blood products may take several days and requires much advance planning.
- Rare units that have been frozen require additional processing that is labor-intensive and costly. Units may occasionally break during the thawing process.
- Transfusing rare units takes coordination between the blood bank and anesthesiologist.

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# Plasma—It's Not Just to Fix an Abnormal INR

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While many guidelines exist for the administration of plasma, adherence to these guidelines is known to be poor. Most guidelines suggest a cut-off value for prothrombin time (PT) and/or partial thromboplastin time (PTT) greater than 1.5 times the normal value before considering plasma-product transfusion. Unfortunately, over half of all orders for fresh–frozen plasma (FFP) orders are believed to be inappropriate. The most frequent reason for inappropriate FFP requests is the correction of a prolonged international normalized ratio (INR) in the absence of clinically relevant bleeding. This essentially equates to treating the numbers rather than the patient. This chapter aims to dispel some common misconceptions associated with plasma transfusion.

## Plasma Use

Practically speaking, the vast majority of plasma transfusions are aimed at replacing clotting factors in acquired coagulopathies; namely liver disease, disseminated intravascular coagulation (DIC), warfarin effect, and dilutional coagulopathy. Plasma use has skyrocketed since the advent of massive transfusion protocols (MTP) using a 1:1 ratio of units of packed red blood cells (pRBC) to plasma. There are also several unusual reasons for plasma use, including use as replacement fluid in therapeutic plasma exchange for thrombotic thrombocytopenic purpura (TTP), and use in rare hereditary bleeding disorders for which a purified factor concentrate is unavailable (e.g., Factor V and Factor XI deficiencies). PT and the INR are the most commonly used tests to assess coagulation disturbances, however, translation of these results into risk for clinical bleeding is often controversial. The INR is calculated using the ratio below:

$$\mathbf{INR = (PT\ of\ patient/mean\ PT\ of\ healthy\ subjects)^{ISI}}$$

where ISI = international sensitivity index, which measures the potency of thromboplastin.

The ISI must be updated with each lot of thromboplastin reagent used in the laboratory or disastrous miscalculations can occur in INR determinations. Such

miscalculations can result in inappropriate adjustments in warfarin dose which can than lead to warfarin necrosis and other dangerous complications. The INR was initially developed to monitor vitamin K antagonists, but has been adapted for much wider "off-label" use in gauging the severity of coagulopathies of all causes. However, a number of studies have shown that the INR is not an accurate predictor of clinical bleeding. In addition, preprocedure plasma transfusions are often without merit, as they neither correct prolonged coagulation lab results nor reduce the incidence of clinical bleeding events. Other factors impacting coagulopathy such as body temperature and blood pH should also be considered in addition to coagulation tests, especially in the setting of trauma. Correcting hypothermia and acidosis often has a marked effect in improving hemostasis.

The INR of banked plasma products is often estimated at 1.6, which means that it is unlikely to be useful in correcting minor elevations of the INR (<1.7). Holland and Brooks developed a formula to predict the INR response per unit of plasma transfused:

**INR change = 0.37 (pretransfusion INR) - 0.47**

A number of studies have demonstrated that patients with INR in the range of 1.2 to 2.0 are not at increased risk of bleeding in association with invasive diagnostic procedures. In addition, most patients on vitamin K antagonists with an INR of 2.0 and without clinical bleeding can be adequately reversed with oral or intravenous vitamin K. Segal and Dzik reviewed one trial and 24 observational studies in which the severity of bleeding was investigated for common invasive procedures in the setting of mild INR elevations. These procedures included bronchoscopy, central vein cannulation, femoral angiography, liver biopsy, kidney biopsy, paracenteses, thoracentesis, and lumbar puncture. While the quality of evidence varied in the studies reviewed, the data overall supported the assertion that elevated INR is not predictive of periprocedural bleeding. Other literature reviews have reached the same conclusion.

## Thromboelastography and ROTEM

Thromboelastography (TEG) is a viscoelastic hemostatic assay that is used as a means of testing coagulation efficiency and may help guide transfusion decisions. This point-of-care test has been used most prominently in cardiac surgery, trauma, and liver transplants. TEG offers some benefits above and beyond typical coagulation tests of PT/INR and activated partial thromboplastin time (aPTT) because it also assesses platelet function, clot strength, and fibrinolysis. The reaction time (R value) indicates the time from the start of the test until the clot first starts forming, and it is a reflection of coagulation factor activity. Prolonged R value has been used as an indicator of when

plasma transfusion should be initiated. Rotational thromboelastometry (ROTEM) is a variant of TEG, and can be used in a similar manner. Clotting time (CT) is the ROTEM parameter that correlates with the need for plasma. TEG and ROTEM can provide rapid assessment of the coagulation system, but require specialized training of staff to provide consistent results.

## Massive Transfusion Protocols

Massive transfusion has three primary definitions: (1) replacement of one blood volume in 24 hours (which roughly equates to use of >10 units of pRBC; (2) replacement of half of the blood volume in the course of 2 hours; and (3) bleeding at rates of >150 mL/min. While all of these represent significant blood loss, the rates of bleeding are quite different between definitions. MTPs have their genesis in the military where coagulopathy may be a primary event in gunshot wounds, shrapnel injuries, and crush injuries. Thus, the rationale is to incorporate plasma and thereby coagulation factors earlier in the resuscitation in ratios that approximate whole blood replacement. The 1:1 pRBC to plasma ratio is generally accepted in most MTPs, with possible incorporation of platelets and cryoprecipitate in later packs. Whole blood replacement fell out of favor years ago, largely because the universal RBC type (Group O) is not the universal plasma type (Group AB), and thus Group O whole blood would be transfusing plasma containing naturally occurring anti-A and anti-B antibodies, posing a possible risk of hemolysis. In addition, blood components, pRBC, and plasma have longer shelf lives, thanks to additive solutions and different storage properties when these components are separated. Judicious blood use also mandates that components be replaced according to need, for example, pRBC for oxygen carrying capacity; plasma for coagulation factor replacement, and platelets for thrombocytopenia/thrombocytopathy. The functionality of platelets in whole blood has also been questioned over the years. Due to the substantial logistics of preparing MTP packs with a ratio of 1 pRBC unit : 1 plasma unit, interest in whole blood is rising again. Some hospitals may have multiple versions of MTP based on the patient population, for example, obstetrics/gynecology patients may have different needs than a trauma patient. A sample weight based chart of MTP packs, appropriate for pediatric and adult trauma patients is shown below.

| | 1st Pack | 2nd, 3rd, 5th, 7th Packs | 4th, 6th, 8th Packs |
|---|---|---|---|
| <10 kg | 1 unit pRBC<br>1 unit thawed plasma | 1 unit pRBC<br>1 unit thawed plasma<br>1 unit random platelet | 1 unit pRBC<br>1 unit thawed plasma<br>1 unit random platelet |

| | | | |
|---|---|---|---|
| | | | 1 unit cryoprecipitate |
| 10–20 kg | 2 units pRBC<br>1 unit thawed plasma | 2 units pRBC<br>2 units thawed plasma<br>2 units random platelet | 2 units pRBC<br>2 units thawed plasma<br>2 units random platelet<br>2–4 units cryoprecipitate |
| 20–49 kg | 4 units pRBC<br>2 units thawed plasma | 4 units pRBC<br>4 units thawed plasma<br>1 dose platelets | 4 units pRBC<br>4 units thawed plasma<br>1 dose platelets<br>4–6 units cryoprecipitate |
| ≥50 kg | 6 units pRBC<br>6 units thawed plasma | 6 units pRBC<br>6 units thawed plasma<br>1 dose platelets | 6 units pRBC<br>6 units thawed plasma<br>1 dose platelets<br>1 dose cryoprecipitate |

## MTP Controversies and Issues

There is some controversy whether the use of MTPs is applicable to civilian populations in a nontrauma setting. The military patient population is generally young, otherwise healthy males, whereas a hospital population features multiple comorbidities such as obesity, diabetes, hypertension, hyperlipidemia, obstructive pulmonary disease, etc. While the trauma literature has shown increased survival with MTPs, these results are retrospective and are susceptible to survivor bias. Patients who live longer receive more blood products than those who succumb to their injuries sooner.

MTPs are generally "push driven" in which products are ordered in packs or batches, and laboratory parameters are not utilized to guide therapy. This is in comparison to a "pull-driven" protocol in which laboratory data or TEG guides the transfusion of particular blood products. This leads to the possibility that patients will be given products that they don't really need. There is also potential for volume overload, alloimmunization, and wastage of unused left-over blood products.

In patients of unknown blood type, the textbooks will always state to use Group O negative pRBC and Group AB plasma. However, given the scarcity of these resources,

many MTPs feature Group O positive pRBC (given that 85% of the population is Rh positive) and reserve Group O negative pRBC for women of childbearing age or patients with known anti-D alloimmunization. In addition, MTPs used to account for a lion's share of AB plasma use; however, with the demonstrated safety of using Group A plasma even in cases of unknown blood type, Group AB plasma is seeing more selective use.

Due to the need to prepare MTP packs quickly, many blood banks keep a pack or two worth of plasma already thawed to allow the first 1:1 pack (usually 6 pRBC and 6 plasma units) to be delivered as quickly as possible. Additional pack preparation often starts as soon as the last one is picked up, but may take a little longer to issue due to the thawing time of FFP, which is about 20 minutes but increases with the number of frozen units placed into a thawing water bath. If more units of plasma are thawed than needed, the FFP can be relabeled as thawed plasma (TP) described below. However, if other patients are not able to use this product, it is often wasted. The same is especially true of cryoprecipitate which has only a 4-hour shelf life after thawing and pooling and is usually wasted if not used for the MTP patient. During massive transfusion, there needs to be good ongoing communication between the OR and the blood bank to best meet the patient's needs while reducing unnecessary wastage.

## Are Guidelines Effective?

While the literature seems compelling, and guidelines are available, enforcement of guidelines has been lacking and often "eminence-based" practice supplants "evidence-based." It is a worthy goal to decrease transfusion, not only to save costs, but to also decrease morbidity by avoiding unnecessary exposure to potential infectious risk, and by reducing events such as transfusion-related acute lung injury (TRALI), transfusion-associated circulatory overload (TACO), and transfusion-related immune modulation (TRIM). Tavares et al. took a three-phased approach to achieve a reduction in plasma transfusion. This group used a 3-year period as a baseline; introduced guidelines and employed education during a second three year period; and finally restricted plasma transfusion to guideline indications over the last 3-year phase. During the baseline period of the study, they found that >50% of all requests for prophylactic plasma transfusion were based on treating INR <2. The education phase introduced guidelines that emphasized the futility of transfusing plasma for INR <2, and encouraged reversal with vitamin K in patients taking warfarin when time and the clinical situation allowed. The guidelines did allow for physician discretion in the following scenarios: lumbar puncture patients with an INR >1.5, and patients with active bleeding and possible dilutional coagulopathy. During the 3-year enforcement phase, requests falling outside of guidelines were referred to the Medical Director of the Blood Bank and assessed on

a case-by-case basis before plasma would be issued or denied. At the end of the 9-year study, there was an 80% reduction in plasma transfusion with no increase in bleeding events or mortality.

Another strategy that has been used is to incorporate electronic, adaptive alerts providing guidelines and education into computerized physician order entry (CPOE) systems for blood products. This approach appears to decrease, but not eliminate the problem of inappropriate blood-product ordering. The effect of such alerts may be limited due to ordering physician and alert fatigue and the time pressures of caring for patients.

## Types of Plasma Products

When plasma is clinically indicated, there are several varieties of products available. The most commonly known plasma product is FFP. However, plasma frozen within 24 hours after phlebotomy (PF24), TP, solvent-treated plasma, and liquid plasma (LP) are also used.

**FFP** is prepared from whole-blood donation by centrifuging the collected unit to sediment down the red blood cells. Platelet-rich plasma is then expressed into one of the sterile interconnected blood collection bags using a device called a plasma extractor and centrifuged again to sediment down the platelets and most of the plasma volume can be expressed into another bag. FFP is frozen at less than or equal to -18°C within 8 hours of collection. FFP can also be collected by apheresis, by which only plasma would be collected and red cells and platelets would be returned to the donor via an automated device.

**PF24** can be made in much the same way as FFP; however, it is frozen at longer than 8 hours after collection but less than 24 hours after. This is a good option for mobile blood drives in which the collected blood products may not return to the blood center for processing within a time frame to allow for FFP preparation. PF24 is similar in function to FFP, although it contains less Factor VIII. Despite containing less Factor VIII, the Factor-VIII level is still generally within the normal reference range.

Both FFP and PF24 can be stored for 1 year at -18°C. Once either FFP or PF24 are thawed, they must be used within 24 hours, unless they are relabeled as TP. TP may be used for up to 4 additional days for a total 5-day shelf life. Factor VIII and V decrease during this defrosted storage, but still maintain hemostatic levels of coagulation factor activities.

**Solvent/detergent-treated plasma** is a product that is derived from large pools of plasma and is treated with solvent/detergent to inactivate enveloped viruses and has not seen wide use in the United States. LP is yet another product that is derived from plasma that has never been frozen. The shelf life of this product is generally 26 days. LP has

demonstrated a loss of coagulation factors from days 7 through 14 of storage, and cold-induced contact activation of some factors after day 14. LP has not been studied as extensively as the other products. A potential disadvantage of this product includes risks associated with transfusion of viable WBCs such as transfusion-associated graft versus host disease, and cytomegalovirus transmission. Normally freezing plasma kills WBCs, making them nonviable when transfused into a recipient. The effects of leukoreduction on this product are not well known and LP is not widely available in US blood banks.

A typical unit of FFP, PF24, TP, or LP contains 200 to 250 mL of plasma and each mL contains about 1 unit of coagulation factor activity. The volume of plasma collected from whole blood largely depends on the donor's hematocrit. So, units may vary in their coagulation factor content depending on volume. Interestingly, von Willebrand factor levels also vary by ABO blood type with levels varying from highest to lowest in Groups AB, B, A and lastly Group O. Group O individuals have von Willebrand factor levels up to 30% lower than the other blood groups. Plasma is not cross-matched for transfusion, but ABO-compatible units must be given.

## Plasma Dosing

Proper dosing of plasma for coagulation factor replacement is 10 to 20 mL/kg (usually 4 to 6 units in an adult). This dose should raise coagulation factors by 20% or within an acceptable hemostatic range immediately after infusion. However, most plasma orders are based on "guesstimating" the number of units rather than calculating an appropriate dose. This often leads to under or overestimations.

## Alternatives to Plasma

When there is ongoing bleeding due to warfarin-induced elevation in INR, emergent reversal of warfarin is better done with 4-factor prothrombin complex concentrate (4-PCC). Theoretically, 4-PCC should be superior to 3-factor PCC (3-PCC), as both products contain all clotting factors inhibited by warfarin (II, VII, IX, and X); however, 4-PCC contains more factor VII than 3-PCC. Despite this theoretical difference, studies directly comparing the two are lacking in the literature. Jones et al. conducted a retrospective study which compared close to 150 patients who received either 4-PCC or 3-PCC for emergent warfarin reversal in the setting of intracranial hemorrhage, gastrointestinal hemorrhage, or other bleeding associated with a significant drop in hemoglobin. They then utilized a propensity-score–matching approach to adjust for differences between the groups and to minimize bias. After matching, close to 40 patients were assessed. There was no difference in the success rate in achieving the primary outcome of INR $\leq$1.4 between 3-PCC and 4-PCC in both the unmatched (85.7% vs. 90.6%) and matched (84.2% vs. 92.1%) analyses. There was a significant

difference in goal INR achieved favoring 4-PCC (56.3% vs. 90.0%; p <0.02) when baseline INR >4.0.

## Summary

In summary, plasma transfusion is indicated for patients who are bleeding or are about to undergo an invasive procedure with deficiencies in multiple coagulation factors, generally with an INR >2.0. Patients with deficiencies due to liver disease, DIC, and massive bleeding with or without dilutional coagulopathy are candidates for plasma transfusion; however, the clinical picture beyond just the INR should be taken into account. Plasma should never be used purely as a volume expander, to avoid the risk of exposure to infectious disease agents. Albumin and other colloid-based products are a more appropriate choice in this setting. A rational approach to plasma transfusion, taking into account the evidence-based literature, reduces unnecessary transfusions and likely decreases risks associated with blood-product transfusion. Just as with RBC transfusion, there is increased focus on blood-product stewardship and outcome analysis of transfusion practice. The Food and Drug Administration views all blood products as both a biologic and a drug. The decision to transfuse plasma should also be made with the same considerations given to the administration of any therapeutic agent.

### TAKE HOME POINTS

- Plasma is often transfused inappropriately.
- Minor INR abnormalities (INR <1.7) are unlikely to be corrected with plasma transfusion as the INR of banked plasma is generally around 1.6.
- Most patients with an INR <2.0 are at low risk of clinical bleeding as evidenced by numerous studies in the literature.
- Most patients on vitamin K antagonists with an INR of 2.0 and without clinical bleeding can be adequately reversed with oral or intravenous vitamin K, without plasma transfusion if time and the clinical scenario allow.
- Plasma should never be used purely as a volume expander.
- TEG and ROTEM can be used to assess coagulation parameters and potentially to guide transfusion.
- MTP accounts for much plasma use in hospitals and is aimed at reapproximating whole blood with a 1 unit pRBC to 1 unit of plasma ratio. MTP is used when there is massive bleeding due to trauma or other causes of hemorrhage, with the goal of reducing associated dilutional coagulopathies.

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# Plasma Part II: Is This Plasma or Pea Soup?

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You are rolling along with your day in the total joint replacement room and your second patient is a 52-year-old man with Child C cirrhosis who is undergoing revision of a total hip arthroplasty. Intraoperatively, she had required transfusion of four units of packed red blood cells. The surgeon requests that you administer fresh–frozen plasma before insertion of the new hardware. When the plasma arrives, you notice that it has a murky and pronounced green color. You hold it up to another unit of plasma and there is no mistaking the difference. You start asking your anesthesia colleagues if they would give it and they all say no. Several people state their suspicions that the plasma might harbor infectious pathogens, particularly the **Pseudomonas** species. One colleague mentions that they had returned such a unit to the blood bank the previous week. **What do you do?**

You transfuse the unit of green plasma. **It poses no additional risk to the patient.**

The clinical vignette above is based on an actual incident. The anesthesiologist adamantly refused to transfuse the plasma in spite of reassurances from the Transfusion Medicine service that it was safe to do so. He sought the opinion of multiple perioperative providers who concurred with his decision not to use the plasma. This valuable resource was unfortunately eventually wasted.

The normal yellow color of plasma arises from the presence of yellow pigments such as carotenoids, hemoglobin, and iron transferrin. The first reports of "green plasma" arose in England in the 1960s. Green plasma was appearing in blood banks in fairly significant numbers and was estimated to be 1% of all units in some large blood centers.

Contamination by gram-negative cryophilic bacteria such as the Pseudomonas species was a decreasing concern 20 years into the antibiotic age and did not explain the relatively sudden increase in the number of green units (Fig. 49.1).

**Figure 49.1.** Fresh frozen plasma units demonstrate the wide variation of possible colors of plasma that is safe for transfusion. (Reprinted with permission from Elkassabany NM, Meny GM, Doria RR, et al. Green Plasma—Revisited. Anesthesiology. 2008;108(4):764–765. Copyright © 2008 the American Society of Anesthesiologists, Inc.)

It was already known in the 1960s that sera obtained by patients with long-standing rheumatoid arthritis was "less yellow" due to decreased amounts of the yellow pigments. But the thousands of green units appearing in England at this time were not from rheumatoid arthritis patients and actually had normal amounts of yellow pigment. Epidemiologic and laboratory investigations ensued, particularly the presence of green pigments.

The donor cohort for the green plasma units was quickly identified as young married women. No green pigment was found, rather a blue precipitate was isolated. This was subsequently identified as ceruloplasmin. Ceruloplasmin is a normal plasma glycoprotein that acts as a carrier for copper. It is also an acute phase reactant. Ceruloplasmin levels are elevated with elevated copper levels in rheumatoid arthritis, and in high-estrogen states such as pregnancy and oral contraceptive use. Further studies identified elevated ceruloplasmin levels in already-processed plasma units. An additional study found high normal or elevated ceruloplasmin levels in 15 donors who were taking oral contraceptives and who had markedly green plasma. Oral contraceptives were just gaining widespread use in the 1960s and that was identified as the most likely cause of the sudden increase in green plasma units. The donor of the

actual unit of plasma shown in the illustration was determined to be a 27-year-old female in excellent health, on no medications, except for a 5-year history of oral contraceptive use. Also, it should be noted that blood collection techniques had advanced, resulting in less hemolysis at the time of donation and therefore less yellow pigmentation from free hemoglobin in the sera.

Green plasma is seen less frequently in OR now that plasma from female donors generally is no longer used for transfusion. This is due to a transfusion-related acute lung injury (TRALI) mitigation strategy, as causative antibodies against human leukocyte antigen (HLA) that tend to form during pregnancy. It is still occasionally seen in donors with rheumatologic diseases.

Another variation of plasma color that may be seen in a donor unit rarely is an off-white hue due to lipemia. A high concentration of lipids and triglycerides may lead to this phenomenon. Having a high fat meal prior to donation, high triglyceride levels, and smoking may predispose to a turbid plasma donation. These units may appear turbid and cause concern for the infusing provider. Blood donations with turbid or milky-appearing plasma are often discarded, even though the lipemia itself does not alter the safety or efficacy of the product. Policies regarding acceptance or rejection of such units varies between blood centers.

Plasma units undergo visual inspection by both regional and hospital transfusion medicine staff using a visual inspection standard published by the American Red Cross.

Anesthesiologists and other providers should be aware of the acceptable variations in physical properties of blood products. They should refrain from refusal to transfuse blood products without consultation with their transfusion medicine service and/or consulting the online resources pertaining to national blood banking guidelines and standards.

## TAKE HOME POINTS

- Plasma units may vary from the "typical" yellow appearance due to decreased amounts of the normal yellow pigments in plasma or the presence of other colored pigments.
- Anesthesiologists will sometimes encounter plasma or platelet units with a distinct green appearance. These units appear green due to the presence of ceruloplasmin, which is commonly elevated in women on oral contraceptives.
- Green plasma is less commonly seen in the OR, now that TRALI mitigation strategies have decreased the use of plasma from female donors. However, apheresis platelets from female donors are used, and as such the platelets are suspended in plasma. If the plasma is discolored, a platelet unit would also be discolored.

- The plasma may be transfused as per normal protocols.

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# Remember That the "Universal" Donor Is Different for Red Cell and Plasma Products

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The concept of a "universal" blood donor is one that is commonly associated with red blood cell transfusions. People who are of the O-negative blood type are considered to be "universal" donors for red blood cell transfusions because their red cells do not possess A or B antigens or the Rh antigen. Therefore, the red cells from O negative individuals lack the antigens to which the transfusion recipient may possess (or form) antibodies. However, you must remember that there are other blood components that are commonly transfused other than red blood cells, such as plasma. An important concept to explore is how the "universal" red blood cell donor is different from the "universal" plasma donor.

Unlike red cell transfusion compatibility that is dependent on what **antigens** are present on the donor red cells, plasma transfusion compatibility is dependent on what circulating **antibodies** are present in the donor plasma. For example, an O positive donor has red cells with only the Rh antigen. The same patient's plasma would contain both anti-A and anti-B antigens due to presumed past exposure to both the A and B antigens. Therefore, transfusing type O plasma that has a large amount of anti-A and/or anti-B antibodies to a patient with type A, B, or AB blood can result in a transfusion reaction due to donor antibodies binding recipient red cells. By this same principle, a type AB donor would lack anti-A and anti-B antibodies due to these antigens being present on their own red cells. This lack of red cell antibodies makes AB plasma the "universal" plasma. **For plasma transfusions, the Rh status of the donor has been shown to be of no significance.**

Unfortunately, the availability of "universal" type AB plasma can be a hindrance to its utility. The pool of available donors is very small, with only 4% of the United States population having type AB blood. The demand for "universal" plasma has also increased in recent years with the advent of new massive transfusion protocols advocating equal ratios of red cell to plasma transfusions in the acute resuscitation of trauma patients. Unfortunately, further complicating this issue were studies done in the

early 2000s showing an unacceptably high incidence of transfusion-related acute lung injury (TRALI) related to the use of AB plasma. A large contributing factor was that plasma from female donors was being pooled with that from male donors due to insufficient type AB blood donors. Females are known to have significantly greater risk of white blood cell alloimmunization with HLA and HNA antibodies, largely due to bearing children. These HLA and HNA antibodies are associated with the development of TRALI. In 2007, the American Red Cross began preferentially using plasma derived from male donors or nulliparous female donors, which has greatly reduced the incidence of plasma-transfusion–associated TRALI for type A, B, and O plasma transfusions. The TRALI incidence for AB plasma transfusions has not decreased due to high demand for this "universal" plasma and the need to continue pooling suitable donor plasma with that from parous females to meet this demand. In situations where blood products are needed urgently, as in the resuscitation of trauma patients, safer, more readily available "universal" plasma is needed.

Recent literature has pointed to the use of group A plasma as a potential new "universal" plasma for trauma patients due to the scarcity of safe, type AB plasma. This strategy is controversial because of the potential increase in transfusion reactions related to incompatible transfusions, for example, a patient with group B blood receiving group A plasma that may have high anti-B titers. Currently, there are insufficient data to definitively comment on the safety of group A "universal" plasma. However, it appears that the risk of transfusion reactions is low and in acutely ill patients, such as trauma patients; this risk is offset by the ability to more quickly administer plasma as part of the initial resuscitation, which has been shown to improve outcomes.

Thus far, the focus of this chapter has been on "universal" blood products given when a patient's blood type is not known. However, once a patient's blood type can be determined, it is important to change to type-specific blood products if available. Multiple studies have shown increased mortality related to non–type-specific transfusions as well as increased risk of acute respiratory distress syndrome (ARDS) and sepsis. The principles underlying plasma compatibility are described above, and the following table lists, in order of preference, which plasma types can be transfused to patients with each blood type (Table 50.1).

In conclusion, the "universal" red blood cell donor is distinctly different from the "universal" plasma donor. The concept of group A plasma as a new "universal" plasma has the potential to expand the availability of plasma for patients requiring transfusion before a type and screen can be performed. As outlined above, there are unique problems that face plasma transfusions, and it is important for anesthesia providers to be aware of these so that informed transfusion decisions can be made quickly in

consultation with your hospital's blood bank. As with transfusion of red blood cells, once a type and screen can be completed, transfusions should move from "universal" products to type-specific ones to reduce potential incompatibility complications.

**Table 50.1 ■ Preferred ABO Selection Order for Plasma Transfusions**

| Recipient ABO Blood Group | Donor ABO Blood Group | | | |
|---|---|---|---|---|
| | 1st Choice | 2nd Choice | 3rd Choice | 4th Choice |
| O | O | A | B | AB |
| A | A | AB | B[a] | O[a] |
| B | B | AB | A[a] | O[a] |
| AB | AB | A[a] | B[a] | O[a] |

[a]Plasma types with "a" represent incompatible transfusions.

## TAKE HOME POINTS

- The "universal" red blood cell and plasma donor blood types are not equivalent.
- O negative red blood cells are considered "universal" because they lack group ABO and rhesus antigens.
- Type AB is considered to be the "universal" plasma donor due to the lack of anti-A and anti-B antibodies in the donor plasma.
- The scarcity of suitable AB plasma donors has led to increased risk of TRALI with AB plasma transfusions due to pooling plasma from parous females who have higher antibody titers than male or nulliparous female donors.
- In situations where plasma is needed urgently and AB plasma is unavailable, plasma from blood type A donors with low anti-B titers can be administered as a "universal" plasma.
- Once the patient's blood type can be determined, type-specific blood products should be administered.
- For plasma transfusion, the Rh status of the donor has been shown to be of little to no clinical significance.

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# Platelets—Often a Mystery!

Gerhardt Konig, MD

Platelets for transfusion come from two sources, either from individual units of donated whole blood or directly from a donor in a 1- to 2-hour cytapheresis procedure. A given amount of platelets is called a "unit," but this term is used quite loosely both in clinical practice and in many guidelines on platelet transfusion. **What exactly is a unit of platelets?** When a patient would benefit from platelets, how many "units" should we give them? Furthermore, what kind of immune response can be expected from platelet transfusions? The goal of this chapter is to clarify the concept of platelet dosing for the anesthesiologist, who often orders and administers platelets directly.

There are in fact three different units of platelets. **Whole-blood–derived platelets** were separated from an individual unit of donated whole blood. The amount of platelets found in a whole-blood–derived unit is too low for an adult and are generally manufactured into pooled or prepooled platelets. An individual whole-blood–derived platelet may sometimes be used as a pediatric platelet dose. Another unit of platelets stored in the blood bank are units of **apheresis platelets**, platelets taken from a single donor in a 1- to 2-hour cytapheresis procedure. These units are released and transfused directly to patients. A third unit of platelets is a unit of **pooled or prepooled platelets**. Units of pooled platelets are made in the blood bank by combining together units of stored whole-blood–derived platelets, and then released to be transfused to patients within 4 hours due to increased risk of bacterial contamination from pooling in an open, nonsterile system. Newer transfusion medicine technologies allow for "prepooling" of platelets in a closed, sterile system, allowing for a full 5-day shelf life of the product. Let's examine each of these three types of platelet units in more detail.

When platelets are separated from individual units of donated whole blood, they are referred to as random-donor platelets or whole-blood–derived platelets. They are separated from the rest of the components within the whole-blood unit by centrifugation, suspended in 50- to 70-mL plasma, and stored in the blood bank. Units of whole-blood–derived platelets contain at least $5.5 \times 10^{10}$ platelets, although most units contain significantly more than this, usually 10 to $25 \times 10^{10}$ platelets. This is part of the problem with the term "unit," in that there is significant variability in the amount of platelets in

each unit, due primarily to the wide variability in the platelet counts of blood donors. Blood bank guidelines state that at least 90% of the units of whole-blood–derived platelets need to contain at least $5.5 \times 10^{10}$ platelets, but they meet this requirement by measuring the platelet count of subsets of all of the units that the blood bank produces. In other words, individual platelet units do not have their platelet counts recorded, so you are never sure how many platelets are in a single unit, besides knowing that it is at least $5.5 \times 10^{10}$, but probably somewhere between 10 and $25 \times 10^{10}$.

Units of pooled platelets are produced in the blood bank by combining together units of whole-blood–derived platelets. A unit of pooled platelets may be produced on demand for a specific patient to create a single bag that contains enough platelets to have a desired therapeutic effect. More commonly, they are now "prepooled" in a closed, sterile system to allow for the full shelf life. Transfusing a single unit of whole-blood–derived platelets will typically not raise a patient's platelet count enough for a therapeutic effect, so units of pooled platelets are produced in the blood bank and sent up to the hospital floors for transfusion to patients by nursing staff. Typically four to eight units of whole-blood–derived platelets are combined together to form a unit of pooled platelets, resulting in a dose of approximately 30 to $60 \times 10^{10}$ platelets per unit of pooled platelets.

A unit of apheresis platelets are collected from a single donor in a 1- to 2-hour cytapheresis procedure. According to blood banking standards, each of these units contain at least $30 \times 10^{10}$ platelets. These units are stored in the blood bank and released directly for transfusion to platelets, as they typically have enough platelets per unit to have a therapeutic effect.

Now that the three types of platelet units have been described, we are ready to discuss platelet dosing. Platelets are given in two broad scenarios: to curb bleeding (therapeutic) and to prevent bleeding (prophylactic). Unfortunately, the optimum platelet dose is not well defined for either situation. There are no specific guidelines on therapeutic platelet dosing, and for prophylactic platelet dosing data exist showing no difference in rates of subsequent bleeding between the so-called "low" and "high" dosing ($11 \times 10^{10}$ vs. $44 \times 10^{10}$ platelets per square meter of body surface area). Therefore current recommendations for both therapeutic and prophylactic indications are to transfuse a single apheresis unit or equivalent pooled unit. The expected response is an increase in the platelet count in a 70-kg adult by 30 to 60,000/μL.

Platelets are generally selected based on plasma compatibility rather than strict ABO matching. ABO antigens are weakly expressed on platelets and matched platelets may produce a more effective response, particularly in group O patients who may have high titers of anti-A or anti-B in their plasma. In practice, though, group-specific platelet transfusions might not be pursued until a patient is deemed unresponsive to platelet

transfusions (platelet count does not increase as suspected). Furthermore, platelet transfusions may lead to HLA alloimmunization and for patients who may, at some future date, require bone marrow or solid organ transplantation, leukoreduced platelets are indicated to minimize this risk. Many larger hospitals have implemented universal leukoreduction of blood products. Leukoreduced products are also considered CMV-safe, as CMV (cytomegalovirus) is harbored in white blood cells.

It is worth discussing patients who present for urgent or emergent surgery who are on platelet inhibitors (aspirin or ADP receptor inhibitors, such as clopidogrel or ticagrelor). Platelet transfusions have been shown to have beneficial effects in platelet aggregation in these patients, but specific guidelines for dosing do not exist, as the effects depend largely on the type of platelets (fresh vs. stored), volume transfused, and concentration of circulating platelet inhibitors at the time of transfusion.

## TAKE HOME POINTS

- There are three different "units" of platelets.
- Whole-blood–derived unit of platelets: platelets that are separated from individual units of donated whole blood (usually manufactured into pooled platelets to create an adequate "dose").
- Pooled or prepooled unit of platelets: units of pooled platelets are produced in the blood bank by combining together units of whole-blood–derived platelets.
- Apheresis unit of platelets: collected from a single donor in a 1- to 2-hour cytapheresis procedure.
- There is no well-defined specific dosing for platelet transfusion. Common practice is to transfuse either one unit of apheresis platelets or the equivalent amount of pooled platelets (four to six units of whole-blood–derived platelets) and check for a response.

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# Cryoprecipitate—The Most Misunderstood Product in the Blood Bank

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The full name of cryoprecipitate is cryoprecipitated antihemolytic factor (AHF), but everyone calls it "cryo" for short. For a product that comes in such a small package, it is unfortunately the most misunderstood product in the blood bank. Many people mistakenly believe that it is just a more concentrated form of fresh–frozen plasma (FFP) but this far from accurate. Most conversations between clinical providers and transfusion medicine professionals regarding this product revolve around this misconception, as providers may favor cryoprecipitate for its small volume in a patient sensitive to volume overload. Few realize that plasma may actually be a better source of the stable factors (Factors V, VIII) diminished in the coagulopathic patient they are caring for. Each unit of cryoprecipitate is made by thawing a single unit of FFP at 1° to 6°C. Certain plasma proteins precipitate out of the solution during the thawing process. The supernatant is removed which leaves behind the cryoprecipitated factors and about 10 to 15 mL of plasma. The supernatant plasma can be used as plasma cryoprecipitate reduced which may be used in refractory thrombotic thrombocytopenic purpura (TTP) as a source of plasma that is low in the prothrombotic von Willebrand factor multimers. While cryoprecipitate is derived from plasma proteins that precipitate out of FFP after thawing, it does not contain all of the coagulation factors found in plasma. As one blood banker puts it—"It is a mere shadow of FFP." In fact, it is only a good source of Factor VIII:C (procoagulant activity), Factor VIII:vWF (von Willebrand factor), fibrinogen, and Factor XIII. A unit of FFP contains approximately 1 international unit (IU) of all coagulation factors per mL except for fibrinogen, of which it contains approximately 400 mg in a standard-sized unit of approximately 200 to 250 mL. Each unit of cryoprecipitate contains only 20% to 30% of the Factor XIII, 40% to 70% of the vWF, and about 30% of the fibrinogen found in the original FFP unit. Quality control measures mandate that each unit of cryoprecipitate contains 80 to 120 units of Factor VIII, at least 150 mg of fibrinogen (and in reality closer to 250 mg), and 20% to 30% of the Factor XIII in the original plasma unit. It also contains approximately 40% to 70% of vWF that

was contained in the original plasma unit. Each unit of cryo is about 10 to 15 mL and it is stored at -18°C or colder for up to 1 year. Due to the inconvenience and potential waste in spiking small volume bags, cryoprecipitate is pooled into larger units before issue to the clinical provider. To make useful doses of cryoprecipitate, 5 to 10 units are typically pooled into a larger bag. Thawing and pooling cryoprecipitate usually takes about 30 minutes. Thawed, pooled cryoprecipitate has a shelf life of only 4 hours. If the product is not used for the original patient for whom it was ordered, it is unlikely to be used for another patient and is often wasted. Hospital purchasing costs for an individual unit of cryoprecipitate average about $40 and a prepooled dose of five units averages around $300. Once indirect costs such as labor and hospital overhead are applied to the base cost to obtain the product, a single unit of cryoprecipitate costs the blood bank around $80 and a prepooled dose around $430. Additional costs are incurred if single units need to be pooled to form an on-demand pool as well. The 2017 Medicare Reimbursement rates show that an individual cryoprecipitate unit is reimbursed at $53, which is approximately $27 less than the cost to the institution. Based on this transfusion medicine specialist's experience at a midsized academic center, our hospital blood bank maintains a cryoprecipitate inventory of approximately 50 units of group A, AB, B, and O each and an inventory of prepooled, frozen 5 unit packs of between 20 and 30 units for groups A, B and O. Group AB donors are more typically reserved for plasma, and little cryoprecipitate is further processed from these donors, making it a less available product.

## Uses of Cryoprecipitate

The main indications for cryoprecipitate are treatment of congenital or acquired fibrinogen deficiency. As a source of fibrinogen, cryoprecipitate is an ideal product. A standard dose of 10 bags deliver about 2,500 mg of fibrinogen in a small 150-mL volume, whereas greater than a liter of FFP would be needed to administer the same quantity. It is often employed in clinical settings with high rates of bleeding and/or altered hemostasis such as cardiac surgery, trauma, liver transplantation (LT), or obstetric hemorrhage. It may also be used in patients with low fibrinogen due to disseminated intravascular coagulation (DIC), which can be secondary to a number of primary diseases such as sepsis, malignancy, and amniotic fluid embolus. So, cryoprecipitate may have a roughly equal likelihood of being used in the ICU as it would for being used in the OR. Fibrinogen is a key component of the coagulation cascade not only in its role in the formation of a fibrin network (with the help of thrombin and factor XIII). It is also involved in the activation of platelets and their subsequent aggregation making it the most important coagulation protein affecting clot stability. A study in 2007 examined changes in hemostasis markers during the course of

postpartum hemorrhage (PPH) in an effort to predict severity. Women with severe PPH had significantly lower fibrinogen, factor V, antithrombin activity, protein C antigen, and prolonged prothrombin time compared to women with nonsevere PPH. In multivariate analysis, fibrinogen was the only marker associated with the development of severe PPH. Massive obstetric bleeding often features low fibrinogen and dramatic fibrinolysis, particularly in emergency cases such as placental abruption, placenta previa, genital tract trauma, and uterine atony. Many obstetric postpartum bleeding protocols include cryoprecipitate and most transfusion medicine specialists would recommend its use earlier rather than later in such cases, particularly if there is concern for DIC. Fibrinogen depletion in episodes of massive hemorrhage is often made worse by resuscitation with crystalloids and or colloids. In the acquired coagulopathy of trauma, experiences from military damage control resuscitation have led to an increase in the ratio of plasma transfusion to red blood cell transfusion. A study of combat casualties in 2008 found that a high ratio of fibrinogen to RBCs was independently associated with improved survival to hospital discharge. To achieve this, the authors proposed transfusing one 10-unit bag of cryo for every 10-unit RBCs, or at least 1 unit of FFP for every 2 units of RBC. If a 1:1 plasma to RBC ratio is employed, fibrinogen and other coagulation factors should be adequately replenished; however, cryoprecipitate may be included in some hospitals' massive transfusion protocol (MTP) part of the predetermined packs or in response to monitoring of thromboelastography (TEG). The European guidelines on the management of bleeding after major trauma advocate for fibrinogen concentrate or cryoprecipitate in the presence of significant bleeding with a plasma fibrinogen level of 1.5 to 2 g/L irrespective of the transfusion strategy. MTPs are usually either "push-driven" in which predetermined packs are distributed to the patient without regard to laboratory values or "pull-driven" in which blood products are dictated by real-time CBC, coagulation values, and TEG results. "Push-driven" protocols sometimes rely on soft signs such as "oozy bleeding" rather than evidence-based data to guide transfusion therapy. Cryoprecipitate may be part of either type of protocol. Unfortunately, "push-driven" MTPs which include cryoprecipitate often result in much wastage of this product as cryoprecipitate only has a 4-hour shelf life once it is thawed and pooled. If the cryoprecipitate is not used for the trauma patient, it is unlikely to be used for any other patient as the indications for cryoprecipitate are few. Also, despite the desire for a 1 pRBC to 1 plasma unit ratio in MTPs, red blood cells are often transfused first and the plasma-containing products lag behind with cryoprecipitate essentially being forgotten at the bottom of the blood cooler.

In cardiac surgery, a small study (30 patients) undergoing aortic surgery was treated with either FFP or FFP and cryo. Patients that were transfused cryoprecipitate had less

blood loss and required fewer units of FFP. A more recent, retrospective study looked at over 3,000 patients who underwent cardiac surgery of which greater than 50% required a blood transfusion. The authors utilized propensity matching (22 characteristics) to compare the group that was and was not transfused. Within the transfused group the type and amount of blood was also compared. The authors concluded that blood transfusion, specifically cryoprecipitate, was independently associated with increased 5-year mortality which gives pause to widespread to widespread indiscriminant use in cardiac surgery.

Patients with liver disease often have dysregulated coagulation based upon deficiencies of both procoagulant and anticoagulant factors as well as thrombocytopenia. In a small study (n = 17), patients with liver disease received either 4 U FFP or 5 U cryoprecipitate. Cryoprecipitate did improve coagulopathy; however, FFP showed greater improvement in the international normalized ratio and activated partial thromboplastin time parameters. In addition, patients in the FFP group received fewer blood products than those receiving cryoprecipitate. Cryoprecipitate is often used in liver transplant as a rich source of fibrinogen; however, FFP contains both procoagulant and anticoagulant factors which likely makes it the better choice in this patient group. In one study of liver transplant patients with hypofibrinogenemia associated with massive hemorrhage, the authors found that intraoperative transfusion of cryoprecipitate was associated with a larger number of biliary complications. Cryoprecipitate may also be useful in uremic patients who have failed dialysis or desmopressin therapies.

Plasma-derived fibrinogen concentrates are available and are gaining favor amongst clinical providers; however, not all hospitals carry this product. A number of European countries have limited cryoprecipitate use altogether in favor of these newer, purified, pasteurized, fibrinogen concentrates. A systematic review comparing the efficacy and safety of fibrinogen concentrate to cryoprecipitate in bleeding patients found that the available evidence comparing the two therapies was sparse and biased. With the evidence available (however flawed), they found no differences in the effect of fibrinogen level increase, reduction in RBC transfusions, or thromboembolic complications between the two products.

## Inappropriate Uses of Cryoprecipitate

In the past, cryoprecipitate was used for hemophilia A and von Willebrand disease prior to the advent of factor concentrates; however, now with so many viral-inactivated, FDA-approved factor concentrates available, using cryoprecipitate for this purpose would be unusual unless alternatives are unavailable. The FDA's Circular of Information for the Use of Human Blood and Blood Components lists cryoprecipitate

for these uses as only a second-line therapy. In much the same way, it was used to prepare topical fibrin glue by mixing cryoprecipitate with a source of thrombin (usually bovine). This preparation posed the risk of patients developing antibodies to bovine Factor V, which can cause clinical bleeding and confuse coagulation test results. In recent years, commercially manufactured fibrin sealant preparations containing human thrombin (e.g., Tisseel) are available and a much better alternative to "home brew" fibrin glue. In rare cases, cryoprecipitate has been used in septic patients to replace fibronectin, which is thought to act as an opsonin for macrophage clearance of noncellular debris. Controlled studies have not demonstrated any benefit and the risk likely outweighs any theoretical benefit.

## Dosing of Cryoprecipitate

Cryoprecipitate does not need to be cross-matched nor ABO compatible, unless the transfusion is being given to a neonate or small infant, as the volume of plasma is generally so small that it would not induce hemolysis in an adult.

When used for Factor VIII replacement, the calculation for dosing bags of cryoprecipitate is:

$$\text{Number of bags of cryo} = \frac{[(\text{plasma volume in mL} \times \%\ \text{increase in Factor VIII needed})/100]}{80}$$

For calculating dosage for fibrinogen replacement:

$$\text{Number of bags of cryo} = \frac{[(\text{plasma volume in mL} \times \text{desired increase in fibrinogen needed})/100]}{250^{*}}$$

*The 250 comes from the fact that each unit of cryoprecipitate contains roughly 250 mg fibrinogen.

The calculations above are rarely performed and most cryoprecipitate requests are made based on guesstimates. The typical adult dose of cryo is 1 unit/5 kg body weight, up to a total dose of 10 units (bags) to achieve a fibrinogen level of approximately 100 mg/dL. The pediatric dose is 1 unit per 5- to 10-kg body weight or 5 to 10 mL/kg. Expectations surrounding dosing assume that there is no ongoing consumption/loss of fibrinogen to decrease its effect. In the setting of consumption, more than one dose may be necessary.

### TAKE HOME POINTS

- Cryoprecipitate is a "mere shadow" of FFP and is not simply a more concentrated

form of plasma.

- The only appropriate uses of cryoprecipitate are treatment of congenital or acquired fibrinogen deficiency or Factor XIII deficiency.
- With availability of better FDA-approved products such as factor concentrates and topical fibrin sealant, it would be unusual to use cryoprecipitate for treating hemophilia, von Willebrand disease, or as a topical fibrin "glue."
- Most cryoprecipitate dosing is guesstimated in units of 10 as a starting dose to achieve approximately 100 mg/dL of fibrinogen in an average-sized adult, but more precise calculations are available.
- Cryoprecipitate does not need to be cross-matched nor ABO compatible as the volume of plasma is low, and even incompatible units would not cause hemolysis in an adult. ABO compatible units are, however, recommended for neonates or small infants.

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# Washed Blood Products Are a Source of Confusion—Here's Some Help

Melissa R. George, DO and Sprague W. Hazard III, MD

Washing of blood products is a greatly misunderstood process. The first point of clarification is that only cellular products (packed red blood cells and platelets) can be washed. The purpose of cell washing is to remove as much of the cell suspension fluid as possible, which includes plasma, anticoagulants, and additive solutions. Plasma and cryoprecipitate cannot be washed, as they are liquid products.

Blood components stored in a plastic bag are never quite as physiologic as blood circulating in the body. During the shelf life of red blood cells a phenomenon known as the "red cell storage lesion" occurs. Red blood cells are anucleate and lack mitochondria and are therefore unable to use oxygen to metabolize energy nor produce proteins. The processes required for red cells to maintain hemoglobin in a configuration appropriate for delivering oxygen molecules and maintaining cell morphology conducive to deformation through small blood vessels do, however, require energy. Packed RBCs (pRBCs) are stored at 4°C, which slows metabolic processes and the most common storage solutions contain varying amounts of an energy source (adenine), anticoagulant, and other preservatives to keep the cells viable. The most commonly used additive solutions allow for a shelf life of up to 42 days for pRBCs. During storage, changes occur to red blood cell metabolism and morphology. One important change is damage to the sodium–potassium pump, which results in the gradual release of intracellular potassium into the supernatant. The potassium concentration within the supernatant stored in common blood additive solutions increases linearly from approximately 2 to 45 mEq/L over 42 days. To put it another way—plasma potassium concentrations in stored blood increase approximately 1 mEq/L per day due to passive leakage out of the red cells. Transfusion of one unit of RBC typically results in the delivery of approximately 10 mEq of potassium to the patient. Patients with normal renal function are generally unaffected by this small influx of potassium; however, there are several patient populations that are at risk for transfusion-related hyperkalemia. Neonates are at increased risk for transfusion-related hyperkalemia due their inability to

excrete significant amount of potassium in the urine. To mitigate this risk, blood that is less than 7 days old is generally used. Trauma patients are also at risk for transfusion-related hyperkalemia. It is important to note that these patients are predisposed to hyperkalemia (independent of transfusion) due to crush injuries that breakdown muscle and release potassium, low cardiac output (and therefore decreased glomerular filtration rate), and hypocalcemia. Patients with acute or chronic renal insufficiency are at risk for the modest increase in the extracellular potassium load due to their inability to excrete excess potassium in the urine. This protective mechanism is diminished in patients even with moderately impaired renal function.

Processed units of cellular blood products contain varying volumes of plasma. Units of red cells contain a minimal volume of plasma, whereas platelets contain a much larger volume. As plasma can contain various allergens, this may be an issue in patients predisposed to allergic reactions. Plasma also contains normal immunoglobulins which may cause anaphylaxis in patients with IgA deficiency with antibodies directed against IgA.

The uses of washed blood products most commonly encountered in anesthesiology practice are as follows:

- Depletion of potassium in red cell product for transfusion to a patient with hyperkalemia and renal failure (higher susceptibility to increased hyperkalemia).
- Prevention of anaphylaxis in an IgA-deficient recipient with documented anti-IgA antibodies (if blood from an IgA deficient is unavailable).
- Recurrent severe allergic transfusion reactions that are not prevented by pretransfusion therapy with an antihistamine or steroid.
- Maternal platelets collected for neonates with neonatal alloimmune thrombocytopenia.

With the advent of more electronic ordering systems, washed products may appear as an additional modification to a blood component order. Washed cells are sometimes requested inadvertently, or as was once communicated to this transfusion medicine physician “because washed blood is better than dirty blood.” Some important caveats of cell washing:

- Cellular blood components may be washed with 1 to 2 L of normal saline using a special cell-washing instrument in the blood bank.
- Cell washing is a labor-intensive process and takes about 45 minutes per unit. Therefore, washed products are not available quickly nor are large quantities of washed products feasible.
- Not all blood banks have cell-washing instruments and may not offer washed products or may need to use an even more labor-intensive (and slower) manual process or have to order washed blood from their blood provider, which adds delivery time and added expense.

- A washed pRBC unit will likely not result in the usual 1 g/dL hemoglobin increase as up to 20% of the RBCs are lost in the washing process.
- Washed RBCs demonstrate increased fragility and increased free hemoglobin may be present in the transfused product, which can be an issue for patients with an underlying hemolytic process or pulmonary hypertension.
- Washed red blood cells only have a 24-hour shelf life. If a washed unit is not used for the intended patient, it is unlikely to be used for another patient and is often wasted.
- A washed platelet unit may lose up to 33% of platelets during the process. Platelet functionality is also adversely affected (platelets become activated) and may result in a suboptimal response.

For reasons outlined above, if concern for hyperkalemia is high and blood is needed urgently or in large quantities, washing is not a feasible option. A better solution may be to provide fresher pRBCs, generally meaning blood that is <14 days old or if possible, <7 days old or using other means to control potassium. In general, washed blood products have limited utility. It is important to employ a thoughtful approach in ordering washed blood products, because such products are not necessarily better and actually may be inferior in several regards. Patients with diminished glomerular filtration or trauma patients with hyperkalemia from injury that necessitate large-volume transfusions will require strategies to remove or shift extracellular potassium. If removal of potassium cannot be facilitated by binders or diuretics, renal replacement should be considered.

## TAKE HOME POINTS

- Washing of blood products in an attempt to get "better" blood does not always mean what you think it means.
- Washing can only be done for units of cellular products (RBCs and platelets) and will remove plasma, anticoagulants, and additive solutions.
- Washing is generally done to try to reduce the potassium load given with cellular blood products. It is also done for less common immunologic situations, such as for IgA-deficient individuals if anti-IgA antibodies are present.
- Washing of blood products is time-consuming, costly, and not universally available.
- Washing is also deleterious to the red blood cells, which is not commonly known. It causes red blood cell fragility and decreases shelf life to around 24 hours if not immediately transfused.
- Washing is also significantly deleterious to platelet products. Washing will destroy up to a third of the platelets in a product and decrease the functionality of the platelets that survive the washing process.
- Washed blood products should be ordered sparingly and hopefully after consultation

with the transfusion medicine staff. It is not a stand-alone solution for the patient undergoing a significant hyperkalemic challenge such as major trauma.

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# This TEG Tracing Looks Like a Rorschach Blot … Is It Time for a Transfusapalooza?

Edwin G. Avery IV, MD, Daniel Diaczok, DO, and Melissa R. George, DO

A 53-year-old female with a right-sided renal carcinoma that has infiltrated into both the liver and inferior vena cava is scheduled for surgical resection of the mass. Past medical history is significant for obesity and moderate COPD related to longstanding tobacco use. The anesthetic plan is to have plenty of intravenous access including a multiport central line in the neck as well as invasive arterial blood pressure monitoring with a goal-directed therapy device that can provide advanced hemodynamic parameter monitoring. This monitoring approach is in anticipation of a long, open abdominal procedure with the potential for massive blood loss. About 2 hours into the procedure the surgeon informs you that "we are losing some blood," at the same time the blood pressure drops to a systolic of 47 mm Hg and the goal-directed therapy device is displaying a cardiac index of 1.1 L/min/$m^2$. Following activation of the Massive Transfusion Protocol and an hour-long transfusapalooza with the Level I rapid transfusion system as well as administration of lots of intravenous vasoconstrictors, the blood pressure and cardiac index have stabilized. The surgeon reports diffuse oozing in the entire surgical field and requests a set of coagulation studies be sent off STAT. You are still waiting for a STAT set of coagulations studies sent off over 45 minutes ago but you send another set anyway. Your attending asks you to also send a sample for thromboelastography (TEG) analysis. About 10 minutes later the lab calls and tells you the STAT coagulation studies you just sent are of insufficient blood quantity and cannot be processed; in addition, they tell you that the TEG sample is processing and the results can be viewed in real time on your computer monitor in the operating room. When you log into the TEG screen you see something that looks like a simplified Rorschach blot … is that good or bad? How do you interpret the TEG tracing and how reliable is this technology anyway?

## Introduction

Surgical coagulopathy is common in cardiac, trauma, and liver surgeries and any other procedure where hemostasis "goes off the reservation" for any period of time. Hematology and special coagulation studies from the core lab are important mainstays in assessing the defects in the coagulation system but their turnaround time, even when sent STAT, makes them less useful in an acute situation like the one described in our clinical vignette. The idea to send a TEG is a great one because with some experience you can use the TEG to more rapidly assess what a coagulopathic patient may need to get back into the normal clotting range; this information is usually available within less than 15 minutes after the sample starts processing. A rapid TEG assay is also available but since most of the literature was generated with the standard TEG we recommend sticking with that. This text contains a separate chapter on coagulopathy management in the cardiac section, so the work in this chapter will focus primarily on TEG and less so on rotational thromboelastometry (ROTEM), which is sometimes referred to as the "European TEG" as the authors have a longstanding clinical experience with TEG use and none with ROTEM.

The first thing to know about the TEG/ROTEM is that they can be a very helpful adjunct in determining why a patient is bleeding and which blood components, or bottled concentrates are needed to correct the coagulopathy. There are six randomized controlled trials which establish that a TEG-guided treatment algorithm (vs. physician discretion) is superior in that there is less bleeding and fewer allogeneic blood products administered to the TEG group. Also be aware that it is well documented in the peer-reviewed literature that treating coagulopathic patients without lab and/or TEG/ROTEM-driven algorithms results in significant overtransfusion. The TEG generates a number of different parameters which all have some specificity and a degree of overlap. (We hope you didn't think this TEG stuff was going to be super easy.)

## TEG Sample Processing

TEG samples are processed slightly differently depending on how they are collected. There are only two methods. First, and most common in our practice, is that we collect a whole blood sample from an arterial line after ensuring elimination of the entire dead space volume in the tubing. The TEG sample can also come from a venous line or direct venipuncture. When taken from direct venipuncture it is important to make sure that the first few milliliters of blood are discarded as they will likely contain tissue factor which will accelerate the clotting process and ultimately throw off your results (i.e., make the coagulation process look better than it actually is functioning). The second method of sample processing is for those collected from either an artery or vein (as above) and added to a blue topped tube (citrate containing).

Whole blood, non-citrated samples are transferred to a 1 mL vial containing the

reagent kaolin. Kaolin, the equivalent of pottery clay, serves to increase the surface area of a negatively charged substrate to activate the contact activation pathway and start the clotting cascade. The whole blood and kaolin containing vials are gently inverted approximately five times and then exactly 360 μL of blood is withdrawn with a micropipette. It is important not to vigorously shake the kaolin vials as that will result in shear stress activation of the platelets and again may throw off the accuracy of the observed results. Sorry, the TEG is a very touchy assay and is fraught with several user interface issues that can mess up results and that is a fact you must be aware of when using it. That said there is a newer version of the TEG that has effectively eliminated the lion share of these user interface issues and if you are purchasing a TEG system now we recommend the upgraded newer model. ROTEM also has fewer user interface issues that will affect results. These user interface issues are also bypassed by having the hospital's central laboratory process the samples. The sample is then added to the TEG cup. For citrate containing samples, 1 mL of the blood is added to the kaolin vial and after gentle agitation 340 μL of blood is added to the cup along with 20 μL of calcium chloride to neutralize the citrate. Note that the main advantage of using the citrate containing tube processing method is that the samples do not have to be processed right away (i.e., they can go for a ride in the hospital tube system and sit awaiting processing for some time in contrast to the whole blood samples which should be processed immediately).

Once in the TEG cup the sample is locked into the device. The samples are processed in a disposable cup held within a carriage that is warmed to 37°C and has a disposable pin suspended inside the cup. The carriage holding the cup rotates bidirectionally ever so slightly off center in a slow, precise manner. The bidirectionality of rotation leads to a mirror image of the tracing, somewhat like a Rorschach blot. The disposable pin is attached to a very sensitive tension wire hanging above the sample that can detect even minimal increases in sample viscosity. These increases in viscosity are graphed out by time with time on the x-axis and amplitude, representative of clot firmness, on the y-axis. The final result is the TEG tracing which is accompanied by numerical values that have produced the tracing.

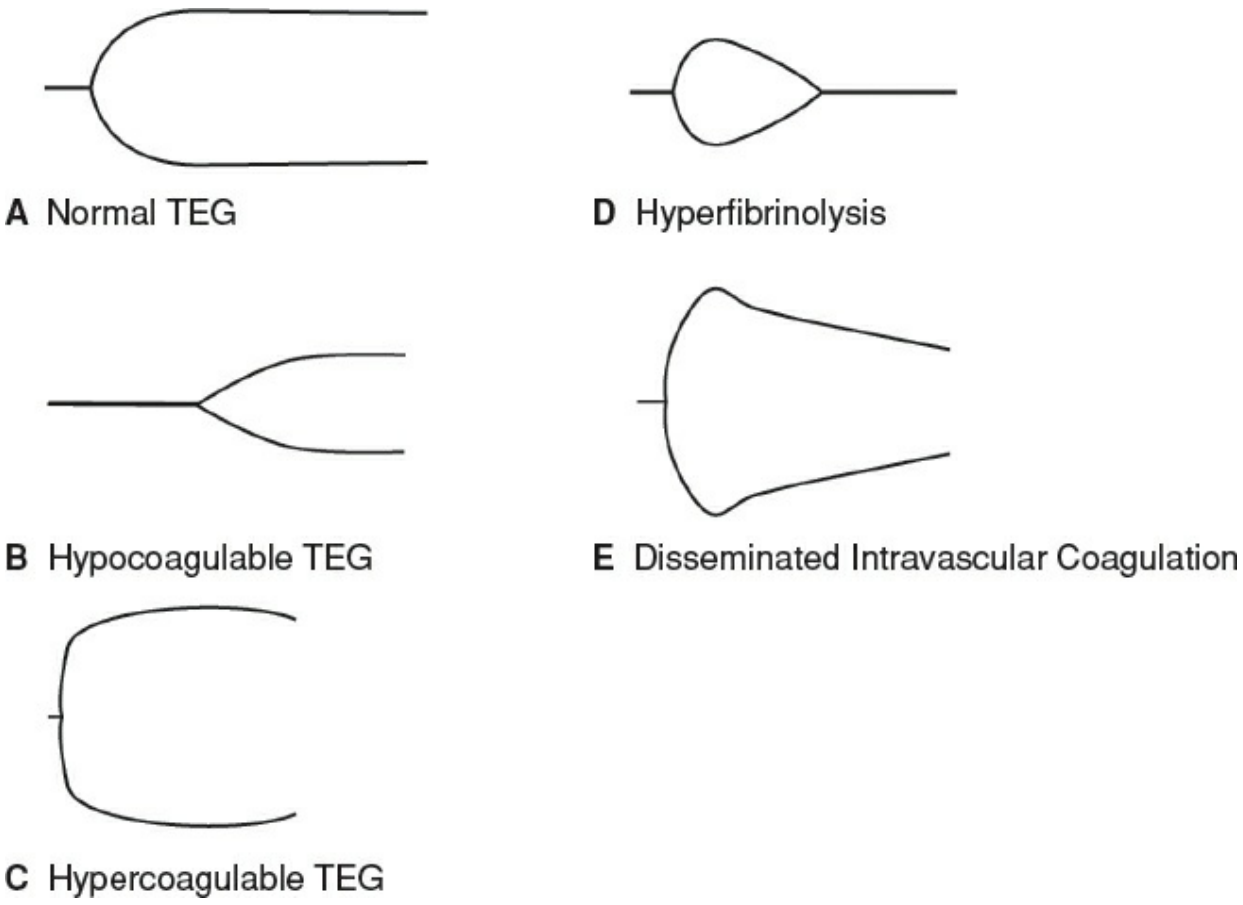


**Figure 54.1.** Common thromboelastography tracings.

**Table 54.1 ■ Normal Thromboelastography Parameters**

| Reaction Time R-Time (minutes) | K-Time (minutes) | Alpha-angle α-angle (degrees) | Maximum Amplitude MA (mm) | Lysis at 30 Minutes LY-30 (%) |
|---|---|---|---|---|
| 4–9 | 1–3 | 59–74 | 55–74 | 0–8 |

A quick look at the TEG tracing will mean a lot to the seasoned clinician as there are a number of common patterns associated with different coagulopathies (Fig. 54.1); however, looking at the various parameters in the context of their normal ranges can also be helpful in coagulopathy assessment for the new TEG user. Following adherence to appropriate sample processing protocols the first parameter that makes up a TEG tracing is the "reaction time" or R-time (Table 54.1). The R-time is the length of time that the sample takes to go from liquid blood to the first detection of clotting (i.e., detection of increased viscosity of the sample).

## TEG Parameters

The R-time largely represents the overall function and/or levels of the soluble

coagulation proteins that comprise the intrinsic, extrinsic, and common pathways. The fibrinogen levels and function also have an influence on the R-time. In addition, anticoagulants such as heparin, coumadin, and direct thrombin inhibitors will prolong the R-time as will low-soluble coagulation proteins levels or function. A relatively hypothermic blood sample (e.g., 33°C) will also have a prolonged R-time even though the TEG warms the sample to 37°C because the warming process is not instantaneous.

In general, when the R-time is prolonged outside of the normal range, clinicians will treat the patient with fresh frozen plasma (FFP). How much FFP depends on how prolonged it is. For example, if the R-time is double the upper limit of normal and the patient has significant clinical hemorrhage, one may give 2 to 4 units of FFP and repeat the TEG.

IMPORTANT: Frequently repeating the TEG is essential to determine if you are making progress treating the coagulopathy.

Alternatively, in the situation where the R-time is 3 to 4×, or more the upper limit of normal, we would approach that in our practice by administering a 500 Unit strength vial of a balanced prothrombin complex concentrate (PCC), also known as KCENTRA (CSL Behring) which essentially contains balanced amounts of the vitamin K–dependent coagulation factors (i.e., factors II, VII, IX, X, protein C, protein S) and a small amount of antithrombin as well as heparin. CAUTION—this is OFF-LABEL use of a balanced PCC as this plasma-derived bottled concentrate is FDA cleared for the reversal of coumarins (e.g., warfarin) in bleeding patients. As with FFP treatment of a prolonged R-time, repeating the TEG at frequent intervals is essential for the safe treatment of any coagulopathy. **Further, it is important to note that there is nothing wrong with correcting a prolonged R-time with just FFP unless you are getting into a volume overload situation which is unlikely if the patient has ongoing hemorrhage.** Indeed, hemorrhaging patients are commonly hypotensive and hypovolemic. If you are in the situation where the R-time is prolonged, several multiples of the upper limit of normal and a PCC is not available, or the FFP is not correcting the problem then the OFF LABEL use of recombinant activated Factor VII (rFVIIa) in a dose as low as 35 µg/kg will commonly acutely reduce the R-time to normal or even below normal (i.e., hypercoagulable).

Because the R-time can be prolonged by coumadin, unfractionated heparin, low-molecular-weight heparin, or direct thrombin inhibitors it is important to know what medications your coagulopathic patient is being treated with. A patient with a prolonged R-time from unfractionated heparin could have the coagulation status normalized with protamine alone. Similarly, a patient on the oral antifactor IIa inhibitor dabigatran can

be corrected with idarucizumab (Praxbind, Boehringer Ingelheim) alone. Use of idarucizumab should be done in consultation with a hematologist unless the administering clinician is well-experienced with the use of this biologic. Idarucizumab will not be effective on neutralizing intravenous direct thrombin inhibitors but a balanced PCC or FFP should be helpful in correcting the coagulopathy. The OFF-LABEL use of rFVIIa may also be helpful if a balanced PCC is not available but thromboembolic complication risk is likely increased.

A final word on the R-time is that related to the fact that the TEG has two different kinds of cups used to process samples, both a plain and a heparinase cup. The heparinase cups are blue in color and contain a small amount of the enzyme heparinase from the gram-negative soil bacterium Flavobacterium heparinum. If a patient's R-time is prolonged from unfractionated heparin then the heparinase containing sample will neutralize the heparin and correct/shorten the R-time for any effect related to the heparin, unless the sample contains more than 4 units/mL of heparin. If there is no heparin effect on the TEG sample the R-times will be the same in both the plain and the blue cups. If the R-time is prolonged related to the presence of low-molecular-weight heparin then protamine administration will only partially correct/neutralize the anticoagulant effect. Bottom line is that in most cases think of the R-time as something that needs to be treated with FFP administration, barring presence of an anticoagulant agent.

The second parameter the TEG sequentially generates is the K-time which is the time it takes to rise to 20 mm of amplitude on the y-axis (Table 54.1). The K-time primarily represents the function or levels of fibrinogen in the sample but it will also be affected (i.e., prolonged) by low-soluble coagulation protein levels or the presence of heparin or direct thrombin inhibitor. The bottom line here is that when the K-time is prolonged beyond the normal range in the presence of clinically significant bleeding, think cryoprecipitate administration as it contains a much higher concentration of fibrinogen than FFP. OFF-LABEL use of the bottled fibrinogen concentrate (RiaSTAP, CSL Behring) may also be indicated in a markedly prolonged K-time but must be administered slowly (approximately 6 to 10 minutes per vial with each vial containing roughly 1,000 mg) and ideally given based on the known level of fibrinogen in the body prior to dosing so that an appropriate increase in plasma fibrinogen levels can be targeted by a manufacturer recommended calculation to avoid a thromboembolic complication. In our practice we target fibrinogen levels greater than 200 mg/dL in patients with clinically significant hemorrhage and a K-time greater than 1.8 minutes. Note that 1 unit of cryoprecipitate per 5 kg of patient weight will increase fibrinogen by about 100 mg/dL. For example, to get an 80-kg patient from a plasma fibrinogen concentration of 100 mg/dL to 200 mg/dL one would need to transfuse (80 kg/5 kg = 16

units of cryoprecipitate).

The next parameter that the TEG will sequentially generate is the alpha-angle (or α-angle) which also represents fibrinogen function/level (Table 54.1). The α-angle is a better indicator of the speed of fibrin accumulation and in our practice we ignore this parameter and look at the K-time. In situations where the plasma fibrinogen concentration is so low that the amplitude never reaches 20 mm of amplitude it will be confirmatory if the α-angle is below the specified normal range. For a below normal range α-angle think cryoprecipitate or fibrinogen concentrate administration.

The fourth parameter that the TEG generates is the Maximum Amplitude, or MA of which 75% of this value is related to platelet function (not platelet number) and 25% of it is related to fibrinogen level. Note that platelet function in vitro (i.e., in the plastic cups reaction vessel) is different than in vivo. Platelet counts below 50,000/mL of blood may still result in normal MA values if all the platelets are functional. Conversely, platelet counts of greater than 200,000/mL of blood will result in normal MA values even when there is significant clinical hemorrhage related to the effect of antiplatelet drugs such as the ADP-antagonists. These agents will not show up as a decreased MA on the TEG. Special platelet mapping assays are needed to gauge the effect of ADP antagonists on the TEG. In this clinical situation we give platelets and fibrinogen as well as DDAVP at a dose of 0.3 μg/kg to mitigate ADP-antagonist–related bleeding. The MA is excellent for identifying platelet dysfunction related to cardiopulmonary bypass induced defects. Bottom line is that for a below normal range MA think platelet administration.

The fifth sequentially generated TEG parameter is the Percent Lysis at 30 minutes (or LY-30). The LY-30 represents the percentage of clot lysis after the sample has reached the MA and is normally less than 8% (Table 54.1). For a high LY-30 value one would consider dosing with an antifibrinolytic agent (e.g., aminocaproic acid or tranexamic acid) if that has not already been done.

A final parameter that some clinicians will consider is termed the clotting index, or CI, which ranges from −3.0 to 3.0. A low CI indicates a hypocoagulable state and a higher value represents a hypercoagulable state. Values around zero are considered normal and it is important to note that the CI value is a collective representation of the R-time, K-time, MA, and LY-30.

## TEG Tracing Patterns and Weaknesses

Figure 54.1 presents a number of common TEG patterns and their associated coagulation abnormalities. Familiarizing oneself with these patterns will partially obviate memorizing the normal ranges for the various TEG parameters. (Hint, hint-like you might see on your written boards). As far as weaknesses are concerned, the TEG

has several and is no different than any other monitor in that its results should not be interpreted in isolation from other clinical variables. For example, in the all too common situation that there is a surgical bleeder that has been missed by the surgeon the TEG will be normal. In this situation you have to just encourage the surgeon to look harder. In our experience correcting a coagulopathy is never as "crisp" as one might like. **I like to explain it as follows—once the TEG parameters have been corrected and the patient is still oozy that it just takes an extra 15 minutes or so for the bleeding to "catch up" with the corrected TEG.** Most commonly the ongoing need for volume and vasoconstrictors will quickly abate once coagulopathic bleeding has been adequately treated, similar to when a brisk surgical bleeder is found and neutralized.

Other weaknesses of the TEG that bear repeating are its inability to absolutely isolate what allogeneic blood components are needed to correct a coagulopathy; this problem is related to the fact that there is some overlap between what all the different TEG parameters are measuring. In addition, processing significantly hypothermic blood samples will result in a TEG with a hypocoagulable profile as mostly all the clotting elements work optimally based upon optimal temperature and pH. Thus, derangements in either of these areas will make the TEG appear hypocoagulable when the patient may really just need to be rewarmed or have their acid–base balance corrected. The TEG is notorious for not being able to reveal ADP-antagonist–related platelet dysfunction unless a special platelet mapping assay is used (same goes for the ROTEM). Also, as previously mentioned the older TEG hardware has a number of user interface issues that require some practice and focus to overcome. Patients being treated with unfractionated or low-molecular-weight heparin or a direct thrombin inhibitor will have a prolonged R-time, K-time, and a reduced MA.

## TAKE HOME POINTS

- TEG/ROTEM can be a very helpful adjunct in determining why a patient is bleeding and which blood components, or bottled concentrates are needed to correct the coagulopathy.
- The peer reviewed literature strongly supports the use of central lab coagulation studies and TEG/ROTEM-driven algorithms to manage surgical coagulopathy.
- TEG samples are processed from either arterial or venous whole blood or a citrated sample of venous or arterial blood.
- When TEG/ROTEM samples are taken from direct venipuncture it is important to make sure that the first few milliliters of blood are discarded as they will likely contain the tissue factor which will accelerate the clotting process and ultimately throw off your results.
- The TEG is a very touchy assay and is fraught with several user interface issues that

can mess up results. A newer version of the TEG and ROTEM are available that has essentially eliminated these user interface issues.

- The TEG/ROTEM can provide useful insight into clotting derangements in less than 15 minutes in most cases. A rapid TEG assay is also available but the majority of the literature was generated with the standard TEG assay so we recommend sticking with that.
- **IMPORTANT:** Frequently repeating the TEG is essential to determine if you are making progress treating the coagulopathy.
- When the TEG R-time is prolonged, think FFP administration.
- When the TEG K-time is prolonged, think cryoprecipitate administration.
- When the TEG MA is low, think platelet administration.
- Don't forget that unfractionated and low-molecular-weight heparin can prolong the R-time and K-time as well as lower the MA.
- Cold patients (i.e., less than 34°C) will bleed and the TEG may be abnormal as well.
- Acid–base abnormalities can also produce a coagulopathy that will be detectable by the TEG but may not require treatment with allogeneic blood components.

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# Transfusion Reactions

Melissa R. George, DO

While the safety of blood products is better than ever, transfusion still carries inherent risks. Transfusion reactions are greatly under-reported and likely under-recognized. Often transfusion reactions are a diagnosis of exclusion and any significant change in a patient's clinical condition during a transfusion should prompt further inquiry. Patients under anesthesia pose particular challenges as the patient cannot verbalize key symptoms such as back/flank pain; however, due to the close monitoring of vital signs and laboratory parameters, potential transfusion reactions should be easily detected. In general, transfusion reactions can be stratified in a number of ways based on clinical symptoms and timing in relation to the transfusion. The serious reactions include: acute and delayed hemolysis, anaphylaxis, transfusion-associated circulatory overload (TACO), transfusion-related acute lung injury (TRALI), and bacterial contamination/sepsis. The less clinically significant reactions include: allergic/anaphylactoid, febrile nonhemolytic, and hypotensive reactions. The incidence of transfusion reactions ranges from:

**Common reactions:**

**Urticaria**—1% to 3% of transfusions
**Febrile nonhemolytic transfusion reaction—**up to 1% of transfusions, but decreasing with more widespread use of leukoreduced products
**TACO—**<1% of transfused patients, more common in patients with underlying cardiac condition and in elderly patients and infants who are more sensitive to fluid shifts
**TRALI—**<0.01% (although likely underreported and percentage may not be reliable

**Rare reactions:**

**Anaphylaxis—**1:20,000 to 1:50,000
**Acute hemolytic transfusion reaction (AHTR)—**1:76,000, usually due to ABO mismatch resulting from clerical error

**Sepsis—**1:50,000 for platelets; to 1:5,000,000 RBCs.

A convenient way to stratify transfusion reactions is the presence or absence of fever coupled with the timing of symptoms in relation to the transfusion as indicated in the tables below.

**Febrile reactions**

| | Diagnosis | Pathophysiology | Treatmen |
|---|---|---|---|
| **Acute** | | | |
| **Acute hemolytic** | Fever, chills, back/flank pain, hemoglobinemia/-uria, bleeding, DIC | ABO incompatible pRBC (usually clerical error), rarely incompatible antibodies in plasma causing hemolysis of recipient RBC | Blood pres volume manage Careful at pretrans patient identific |
| **Febrile nonhemolytic** | Fever (>1°C increase), chills | Cytokines present in transfused unit | Antipyreti meperic severe Provide le product premed antipyre |
| **Bacterial contamination/sepsis** | Rapid onset of high fever, chills, rigors, shock | Bacteria present in unit or introduced through infusion site or line | Treat like antibiot pressure Blood cu possible the tran product New testin bacteria units ma blood re agencie |

| | | | |
|---|---|---|---|
| **Transfusion-related acute lung injury (TRALI)** | Respiratory distress, acute lung injury within 6 hours of transfusion, new B/L pulmonary infiltrates, hypoxemia, CHF ruled out | Recruitment of neutrophils into small vessels of lungs by anti-HLA or anti-HNA in unit or 2-hit hypothesis involving physiologic priming in recipient | Supportive mechan ventilati<br>Use of ma plasma Chapter or scree anti-HL donors |
| **Delayed (>6 hours after transfusion)** | | | |
| **Delayed hemolytic** | Fever, anemia, ≥1 week after transfusion, positive direct antiglobulin test (DAT) | Anamnestic response, preformed antibodies respond to re-exposure to offending antigen | Supportive<br>Identify a provide negativ future |
| **Transfusion-associated graft versus host disease (TA-GVHD)** | Fever, diarrhea, rash, cytopenias, >1 week after transfusion | Transfused T-lymphocytes in product attack host tissues like GVHD plus cytopenias | Supportive<br>Irradiation products at-risk r |

HLA, human leukocyte antigen; HNA, human neutrophil antigen

## Afebrile reactions

| | Diagnosis | Pathophysiology | Treatment/Preventio |
|---|---|---|---|
| **Acute** | | | |

| | | | |
|---|---|---|---|
| **Urticarial/allergic** | Hives (localized or diffuse), itching | IgE-mediated reaction against allergens in blood product (usually plasma proteins) | Antihistamines<br>Potentially premedication with antihistamines, steroids for severe repeat reactions, washed cellular blood products for recipients with breakthrough symptoms refractor to treatments abov |
| **Anaphylaxis** | Dyspnea, hypoxia, angioedema, shock, GI symptoms | Severe IgE-mediated reaction (rarely passively acquired) or anti-IgA reaction in IgA-deficient recipient | Supportive<br>Test for anti-IgA and possible IgA deficiency. Washed cellular products or IgA-deficient products for future transfusion |
| **Hypotensive** | Isolated hypotension during transfusion | Bradykinin metabolism in patients on ACE inhibitors | Stop the transfusion, recovery usually occurs quickly<br>Consider holding ACE inhibitor right befor future transfusion |
| **Transfusion-associated circulatory overload (TACO)** | Dyspnea, hypoxia during or after transfusion, CHF, new pulmonary infiltrates, cardiac dysfunction | Underlying cardiac disease with volume challenge particularly in sensitive populations (elderly, infants) | Diuretics, slow infusions<br>Be mindful of I/O's, space transfusions over time in patient with cardiac disease or otherwise sensitive to volume |

| Delayed (>6 hours after transfusion) | | | |
|---|---|---|---|
| **Post-transfusion purpura** | Unexplained bruising >1 week after transfusion, decreased platelets | Recipient antibodies directed platelet antigens (anti-HPA usually) | Usually resolves on its own, IVIG in rare cases<br>Future transfusion wit antigen-negative platelets |
| **Iron Overload** | Organ dysfunction, increased iron studies | Increased iron load from multiple transfusions | Iron chelators<br>Consider red cell exchange as a more iron neutral option in sickle cell patient |

HPA, human platelet antigen

**Differential diagnosis of transfusion reaction based on symptoms**
**Afebrile reactions**

| Signs and Symptoms | Differential Diagnosis |
|---|---|
| Fever | Underlying condition<br>Febrile nonhemolytic transfusion reaction<br>Acute hemolytic transfusion reaction<br>Bacterial contamination/sepsis or sepsis from other causes<br>Transfusion-related acute lung injury (TRALI) |
| Rash | Urticarial/allergic transfusion reaction<br>Drug reaction<br>Severe allergic reaction/anaphylaxis |
| Multisystem organ failure or shock | Acute hemolytic transfusion reaction<br>Anaphylaxis<br>Underlying condition |
| Hemolysis | Acute or delayed hemolytic transfusion reaction<br>DIC<br>Immune hemolysis—auto antibody, drug-related |

| | |
|---|---|
| | antibody<br>Underlying condition |
| Dyspnea | TRALI<br>Transfusion-associated circulatory overload (TACO)<br>Severe allergic reaction/anaphylaxis<br>CHF<br>Underlying condition |
| Hypotension | TRALI<br>Acute hemolytic transfusion reaction<br>Bacterial contamination/sepsis<br>Hypotensive transfusion reaction<br>Shock |
| Hypertension | TACO |

## Treatment of Transfusion Reactions

As soon as a transfusion reaction is suspected the following steps should be initiated by the clinical team:

1) Stop the transfusion and verify identifiers of the patient and the blood product
2) Keep IV access with normal saline (keep vein open [KVO])
3) Assess the patient according to the tables above
4) Report the transfusion reaction to the blood bank and send the remaining blood product and tubing along with appropriate post-transfusion samples. The blood bank will:
   a. Perform a clerical check of the patient and product information
   b. Perform a visual inspection of the post-transfusion samples for hemolysis
   c. Perform a DAT on the post-transfusion sample
   d. Potentially request urine sample if hemolysis is suspected
   e. Potentially culture the unit if bacterial contamination is suspected
   f. Transfusion-medicine physician will assess the reaction and make transfusion recommendations

### TAKE HOME POINTS

- Any change in the clinical condition of a patient during a transfusion should prompt consideration of a transfusion reaction.

- At the first sign of a transfusion reaction, the transfusion should be stopped.
- Suspected transfusion reactions should be reported to the blood bank for thorough assessment.
- Most transfusion reactions are treated through supportive care.
- Depending on the pathophysiology, preventative steps sometimes can be taken to avoid future reactions.

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# Transfusion Outcomes

Melissa R. George, DO and Sprague W. Hazard III, MD

While transfusions can be life saving, blood products carry inherent risks which can significantly impact both health care costs and patient morbidity/mortality. Numerous recent studies have investigated the outcomes of liberal versus restrictive transfusion strategies with reasonable support for restrictive practices. However, the literature on basic transfusion outcomes remains controversial with early studies plagued by pitfalls such as lack of multivariate analysis of confounding factors. This chapter aims to provide a brief overview of current transfusion outcomes literature with a focus on higher quality studies.

## Varied Practice—Transfusion Triggers pRBC

It is well known that transfusion practice varies quite a bit from institution to institution and even between providers at the same institution. What was previously not well characterized was just how dramatic these variations can be. Frank et al. published on the variability in blood utilization via data gleaned from an anesthesiology information system. This information system had data on hemoglobin values, utilization of blood components, and use of cell salvage for every surgical procedure performed. Hemoglobin triggers and transfusion targets were assessed for different types of surgery with historically high blood use. For primary coronary artery bypass surgery, there was little variation between providers, regardless of the numbers of procedures each individual performed. For Whipple procedures, there was a significant difference among surgeons of almost 2 g/dL difference between the lowest (7.8 g/dL) and highest (9.6 g/dL) hemoglobin triggers and also for targets. Results for posterior lumbar fusion, showed a 1.6 g/dL difference between the lowest and highest hemoglobin triggers, but hemoglobin targets were similar amongst providers. FFP and platelet use among surgeons varied dramatically (threefold to fourfold) for the surgeries referenced. The use of intraoperative cell salvage also varied greatly between providers.

## Why Decrease Transfusion?

## Risk of Nosocomial Infection

While the risk of transfusion-transmitted infectious disease is lower than ever, transfusion has been associated with increased risk of nosocomial infection once confounding variables have been accounted for. Central to this risk is believed to be transfusion-related immune modulation (TRIM). Several mechanisms for this phenomenon have been proposed including:

) Downregulation of the recipient's immune response from WBCs in the product
) Soluble biologic response modifiers released by WBCs during storage of blood
) Soluble human leukocyte antigen (HLA) peptides
) A proinflammatory mechanism by which allogenic blood transfusion contributes to postoperative organ dysfunction, and thus predisposes to infection

The effect of leukoreduction on this phenomenon remains controversial; however, the FDA currently "supports the use of leukocyte-reduced blood and blood components and, seeks to streamline the licensing procedure for leukocytes reduced blood components to assist blood establishments in making pre-storage leukocytes reduced blood components more widely available." A meta-analysis of trials with over 8,500 patients, showed that a restrictive RBC transfusion strategy compared with a liberal transfusion strategy was not associated with a reduced risk of health-care–associated infection overall. A restrictive strategy was however associated with a reduced risk of serious infection. More data are needed to truly assess the risk of nosocomial infection in transfused patients and as such further studies (preferably randomized controlled trials) are needed.

The only well-substantiated effect of TRIM has actually been beneficial in the enhanced renal allograft survival in patients who have received preoperative blood transfusion. Many transplant centers will purposely transfuse patients on the renal transplant list to leverage this effect.

## Cancer Recurrence

Twenty years ago, there was a proposed association between allogeneic blood transfusion and cancer recurrence. Several animal models have suggested a link between mononuclear cells transfused in nonleukoreduced blood and cancer recurrence; however, these models have not translated conclusively to humans. More recent studies with extensive multivariate analysis and adjustment for advances in clinical practice over time have largely debunked this theory in prostate cancer. Yeoh and colleagues studied transfused versus untransfused prostate cancer patients adjusted for the year of operation, patient age, PSA level, tumor stage, Gleason score, adjuvant therapy, and type of anesthesia used (neuraxial block vs. general anesthesia vs. general anesthesia

supplemented by neuraxial block) showed no statistically significant difference between the groups. This was one of the first studies to adjust for the potentially immunosuppressive effect of systemic opioid use lessened by neuraxial block. A similar study also in prostate cancer patients by Chalfin et al., adjusted for the factors above except for the type of anesthesia with the addition of the Charlson comorbidity index showed no association with transfusion and recurrence, cancer-specific mortality, or overall survival. The literature surrounding other tumor types still provokes much debate with no conclusive results. A randomized controlled trial looking at nonleukoreduced versus leukoreduced blood transfusions in the setting of a more immunogenic tumor would be needed for further investigation.

## Cardiovascular Effects

The Transfusion Trigger Trial for Functional Outcomes in Cardiovascular Patients Undergoing Surgical Hip Fracture Repair (FOCUS) tested the hypothesis that a liberal transfusion threshold of Hb ≤10 g/dL would improve recovery, morbidity, and mortality, compared to a restrictive strategy of Hb <8 g/dL. This study found no significant differences between group rates of death or inability to walk without human assistance on 60-day follow-up, and rates of inhospital acute myocardial infarction (AMI) or unstable angina. The Transfusion Requirements after Cardiac Surgery (TRACS) trial found that independent of liberal versus restrictive transfusion strategy, the number of transfused pRBC was an independent risk factor for clinical complications or death at 30 days. This study concludes that in this patient population, a restrictive transfusion strategy was noninferior compared with a more liberal strategy in terms of the outcome of 30-day all-cause mortality and severe morbidity.

The Transfusion Requirements in Critical Care Investigators evaluated the effects of a liberal versus restrictive transfusion strategy in critical care. This randomized controlled study of over 800 patients evaluated the rate of death from all causes in the 30 days after admission to the intensive care unit, and found a statistically significant difference demonstrating lower mortality in the restrictive-strategy group. Mortality rates during hospitalization, during the entire intensive care unit stay, and at 60 days were all lower in the restrictive strategy. Even more striking was that the odds ratio for death within 30 days in the restrictive-strategy group as compared with the liberal-strategy group, even adjusted for age, APACHE II score, diagnosis, and coexisting illnesses was 0.72 ($P = 0.07$). In addition, rates of cardiac complications and other organ dysfunction favored the restrictive strategy. Maintaining hemoglobin concentrations between 7.0 and 9.0 g/dL reduced the number of pRBCs transfused by over 50%.

What about patients who are acutely bleeding? In a study published in 2013, 921

patients with severe acute upper gastrointestinal bleeding were randomized to either a restrictive strategy (transfusion when hemoglobin fell below 7 g/dL) or a liberal strategy (transfusion when hemoglobin fell below 9 g/dL). Not surprisingly, patients in the restrictive group were more likely to not receive a transfusion (51% compared to 14% in the liberal group). What was interesting was that the patents in the restrictive group were less likely to have further bleeding (10% compared to 16%) and the number of adverse advents was significantly less in the restrictive group. The probability of survival at 6 weeks was higher in the restrictive-strategy group than in the liberal-strategy group. The care of acutely bleeding patients is a frequent challenge both in the operating room and in the ICU and this study would suggest that waiting until hemoglobin levels fall below 7 to transfuse is appropriate.

## Red Cell Alloimmunization

Red blood cells house hundreds of antigens. Exposure to foreign antigens can result in red cell alloimmunization. In multiply transfused sickle cell patients, rates of alloimmunization may range from 20% to 50%. This is compared to 2% to 5% of all transfusion recipients. These discrepant rates of alloimmunization can be accounted for, in large part, by the differences in RBC antigen expression frequencies between a predominantly Caucasian donor base and a mostly African-American sickle cell disease patient population. For the general population, while a rate of alloimmunization of 2% to 5% seems low, the consequences are significant in terms of providing matched blood for future transfusions and for women of childbearing age, the risk of hemolytic disease of the newborn.

## Plasma

Most plasma transfusions are used for the treatment of patients with acquired bleeding disorders. There is marked variability in practice and often the transfusion of plasma is based solely on the prothrombin time (PT) and international normalized ratio (INR) rather than the clinical presentation of the patient. Indiscriminant coagulation testing is rampant despite numerous studies demonstrating that these laboratory values correlate poorly with the actual bleeding risk. Patients with minimal INR elevation (1.2 to 2.0) are **not** at increased risk of bleeding during minor procedures. To make matters worse, PT and aPTT have both a high false-positive and false-negative rates that can lead to unnecessary surgical delays and more costly testing. When plasma is transfused for minimal elevations in PT/INR, it often produces no measurable change in laboratory values. Even patients with an INR greater than 2.0 who are taking vitamin K antagonists can achieve adequate reversal with vitamin K therapy rather than plasma. Numerous studies have demonstrated a greater risk of acute lung injury in patients who receive

FFP. Further investigation identified some of these cases as transfusion-related acute lung injury (TRALI) (See Chapter 55) and led to TRALI mitigation strategies which include use of male-only plasma and deferral of apheresis donors with antibodies directed against HLA or human neutrophil antigens (HNA). This strategy has greatly decreased the incidence of TRALI, but some residual risk remains due to recipient factors and cytokines in stored products that may contribute to TRALI via a different mechanism. It would seem that many FFP transfusions incur risks that may outweigh the somewhat questionable benefit of transfusion in these borderline laboratory parameter cases without clinical bleeding. Tavares et al. conducted a 9-year study broken into three study periods: (1) baseline plasma use; (2) soft-stop intervention with recommendations against seemingly unnecessary plasma use but no overt restriction, and (3) hard-stop intervention with denial of requests not meeting established criteria. This intervention resulted in an 80% reduction in FFP transfusion with no unexpected bleeding attributable to lack of FFP transfusion reported.

## Platelets

While transfusion outcomes for platelets have not been studied as intensely as that of red blood cells or plasma, platelet transfusions in platelet consumptive disorders such as thrombotic thrombocytopenic purpura (TTP) and heparin-induced thrombocytopenia (HIT) have been shown to be associated with arterial thrombosis and inhospital mortality. A study by Goel and colleagues of the Nationwide Inpatient Sample evaluated inpatient platelet transfusion practices and their association with arterial/venous thrombosis, AMI, stroke, and mortality over 5 years (adjusting for age and gender). Platelet transfusions in TTP and HIT were associated with higher odds of arterial thrombosis and mortality. Platelet transfusions in TTP were additionally associated with AMI. Past studies have shown conflicting results in patient populations such as those undergoing cardiothoracic surgery. A 2015 study by Kremke et al. of almost 900 patients undergoing coronary artery bypass graft (CABG) demonstrated that platelet transfusion at the time of CABG is not associated with increased postoperative mortality, inhospital myocardial infarction, stroke, or need for repeat coronary revascularization.

## All Blood Products

The use of a liberal transfusion strategy employed by many physicians may reflect a false sense of security based on blood products being “safer” than ever, thanks to sensitive infectious disease testing greatly reducing the viral transmission risks. This cavalier attitude neglects some of the less tangible, but still relevant risks of transfusion such as transfusion reactions (See Chapter 55), immunomodulation, the possibility of

increased nosocomial infection, and alloimmunization.

## Increase in Length of Stay

Veenith and colleagues conducted a study looking at whether perioperative blood transfusion is an independent risk factor for mortality and morbidity in the elderly. This study evaluated close to 875 patients ≥80 years old on the day of their cardiac surgery and found that duration of stay in the ICU and the hospital in general was significantly associated with the amount of blood products administered. The study considered confounding variables using a multivariable logistic regression analysis.

## Increased Costs

A study conducted in Australia demonstrated that transfusions to be associated with a mean inpatient cost that was 1.83 times higher in transfused patients than in a nontransfused group (after adjustment for confounding factors—hospital type, patient age, sex, admission type, discharge type, adjusted diagnosis-related group [DRG], and comorbidities). The estimated total hospital-associated cost of RBC represented almost 8% of total hospital expenditure on acute care patients. In this age of cost containment, practicing evidence-based transfusion practice leading to better patient blood management also has a positive impact on the hospital's bottom line.

## Declining Donor Supply

In 2015, an estimated 11.3 million pRBC units were transfused in acute care hospitals in the United States alone. This was an almost 14% decline since 2013. In a simple law of supply and demand, blood donation centers are adjusting their collections accordingly to not be left with a glut of unused inventory. This poses some logistical challenges as supply and demand oscillate and mass casualty scenarios can easily deplete a region's blood supply, especially in light of fewer available units being on the blood supplier's shelves. There are natural peaks and valleys of blood donation as well with donations decreasing in summer and around holidays with regular donors not being available due to travel or family obligations. Bad weather conditions such as blizzards and severe storms also impact the donor's ability to travel to the donor center. Donor demographic studies suggest that the majority of blood donors are over age 50. This suggests the need for improved recruitment and retention of young adult and middle-aged blood donors. The aging donor population poses additional challenges as older donors may be more likely to develop medical conditions or start taking a prescription resulting in donor deferral. The US blood inventory is based on the altruism of volunteer blood donors. Maintenance of an adequate blood supply hinges on careful stewardship of a precious resource.

Transfusion is life saving under the right conditions. The literature on transfusion outcomes provokes much debate; however, general consensus favors judicious use of blood products and avoiding transfusion when possible, especially in light of declining blood product inventory.

## TAKE HOME POINTS

- TRIM remains a concern and may increase the risk for nosocomial infections in transfused patients.
- Restrictive transfusion strategies have had noninferior or improved outcomes over more liberal transfusion practice.
- Inhospital transfusion may be associated with increased length of stay and costs.

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# Directed Donation Is Generally Not a Good Idea

Melissa R. George, DO

A directed-donor blood product is blood that is collected from a donor, generally a family member or friend, selected by the patient who is to be transfused. Directed donation gained popularity during the early days of the HIV epidemic in the 1980s when fear over blood safety increased interest in this practice. Some people believed that blood from a family member or friend would be safer than units from the general inventory. The percentage of donations from directed donors has declined significantly in recent years from 1.6% in 1995 to 0.12% in 2010 (based on American Red Cross [ARC] data) and has likely dropped even further. Within directed donations, one-half of directed donors have a blood type that is incompatible with the recipient and therefore cannot be used for that individual (e.g., donor is Group A and recipient is Group O). While some may still harbor the notion that directed donation is safer, no evidence-based literature has **ever** demonstrated direct donation to be safer than blood provided from volunteer blood donors. In fact, directed donation may actually be less safe. The volunteer blood supply is extremely safe, especially in terms of risk of viral disease transmission.

## Blood Safety

Currently, the estimated risks of viral disease transmission are outlined below:

**HIV**—1 in 2 million donations
**HCV**—1 in 2 million donations
**HBV**—1 in 205,000

In a study reviewing directed donations made to the ARC from 2005 to 2010, viral-marker–positive rates of directed donations were compared to that of volunteer, community donations. Between 2005 and 2010, the ARC collected over 38 million volunteer donations and close to 70,000 directed donations. Rates of HIV, HCV, HBV, and HTLV for volunteer donations were 2.9, 32.3, 12.4, and 2.5 per 100,000 donations,

respectively, while viral marker positive rates in directed donations were higher at 7.2, 93.0, 40.1, and 18.6 per 100,000, respectively. A 2017 publication looking at approximately 1,500 parental donations, 4,900 nonparental-directed donations, and over 17,000 community donations indicated that the median rate of positive viral marker testing in parental donations was close to 9% for first-time donors and 1.26% for repeat donors. Among nonparental donors, the rate was 1.09% for first-time donors and 0% for repeat donors. Among volunteer community donors, the rate was 2.95% for first-time donors and 0.45% for repeat donors. Thus, during this time frame, first-time parental donations had the highest overall rate of positive infectious disease testing, and first-time nonparental and community donors had significantly higher infectious disease risk than the respective repeat donors. These results were enough to generate a recommendation that first-time parental blood donation should be discouraged. While one would think that a parent would never do anything to endanger their child, fear of scrutiny, family pressure, and lack of knowledge can contribute to inappropriate-directed donation. Based on my own experience in my transfusion medicine service, I once encountered a situation where the mother of a child was pressuring the father of the child to donate blood. The child was found to be hemoglobin S positive, indicating either sickle cell disease or trait. For transfusions to young children, most blood banks routinely screen blood for HbS and provide HbS-negative units. The father of the child did donate a directed unit of blood and was found to be HbS positive, precluding the use of his pRBC for his child. The mother of the child was angry that the father was not eligible as the baby's blood donor. Due to the contentious relationship between the parents of the child, the father requested that I participate in a teleconference between him and the mother of his child explaining why his blood could not be used. With all proper consents and ethical issues considered, the conversation proceeded, but it was eye opening to see a very difficult family dynamic.

While directed donations are screened in the same way volunteer blood donations are, there is still a small risk of blood being collected during the "window period" of about 4 to 7 days in which the viral load is below the level of detection of even highly sensitive molecular testing. So, if a donor engaged in a high-risk behavior during that time frame, but was not yet aware of infection, this product could pass viral testing and be transfused to the recipient. Directed donors are also more likely to be first-time donors, less familiar with donor screening. Blood safety is increased with repeat donation, as donors are aware of the donor questionnaire and infectious disease marker testing used for screening. Donors with repeatedly negative viral marker testing are the safest choice for blood donation. Patients requesting directed donation may also feel pressured to accept blood products from a directed donor whom they know or suspect has health risks.

Arguments against directed donation also include harm to the donor. Unfortunately, directed donors may feel motivated to lie about their risk factors, or medical condition. This may be the result of fear of social disapproval or an altruistic but inappropriate desire to help. Such may be the case if a donor is not feeling well on the day of donation or has medical condition/takes a medication that should preclude donation but proceeds with donation any way. In the event that this donor had a mild bacteremia, there is a chance that he or she may be donating a bacterially contaminated blood product that can cause sepsis in the recipient. In the case of certain medications, there is a risk of teratogenicity should that blood go to a pregnant woman, or there can also be decreased effectiveness of the product in the case of a donor on antiplatelet therapy donating a platelet product. Another example would be a donor who has engaged in male-to-male sexual contact, which per FDA guidance is a 1-year deferral from the time of the last such contact. If that individual has not "come out" to his family, they may not understand why he cannot donate blood. This individual may feel pressured to donate anyway, despite the FDA deferral. Family/peer pressure for directed donation also may jeopardize the confidentiality of the directed donor in the event of deferral for unexpected positive viral marker results.

There are rare exceptions where a blood center may need to collect directed donations. One such scenario is the collection of maternal red blood cells or platelets for transfusion to the fetus or infant for treatment of hemolytic disease of the newborn or neonatal alloimmune thrombocytopenia, conditions in which antibodies from the mother's circulation cross the placenta and attack red blood cells or platelets in the fetus/baby's system. Other rare exceptions are when a patient has an antibody to a high-frequency antigen or needs human leukocyte antigen (HLA)-matched products. In these circumstances, family members may be the best chance of locating a match and an exception would be made. Some have argued that regular donations from a repeat directed donor (provided all other criteria are met) might be a way to decrease the number of donor exposures to a particular patient, reducing the risk of red cell and potentially HLA alloimmunization in patients prone to such complications. A final consideration is that ethically, it would be difficult to justify denying a regular repeat donor the ability to provide directed donation. If this individual is willing to altruistically help strangers, why not allow them to help a loved one?

Prior to initiating directed donation, some practical implications should be discussed with the blood recipient. There are additional costs associated with directed donation, up to 50% more expensive than a regular blood product. If blood is being donated from a blood relative, the blood product must be irradiated to protect the recipient against transfusion-associated graft versus host disease (TA-GVHD), a rare, but largely fatal complication in which the recipient's immune system fails to recognize lymphocytes

contained in the transfused blood product as foreign and allows those lymphocytes to engraft in the bone marrow. These lymphocytes then attack host tissues and produce a graft versus host phenomenon that results in bone marrow aplasia, along with the skin and gastrointestinal involvement that is not responsive to the treatments used in treating post bone marrow transplant GVHD. Also, directed donations require special handling such as being sequestered away from the general blood inventory until it is known that the unit will not be used for the intended patient. At that point in time, the unit can be released into the general inventory if permission to do so was granted at the time of donation. Third-party payers might not cover the extra costs associated with directed donation if it cannot be proven that directed donation was medically necessary.

Knowing the risks, providing directed donation solely because patients request it can be likened to providing an antibiotic for viral illness because the patient wants it. The transfusion medicine community is trying to use evidence-based practice to provide the safest, most efficacious blood products. Based on available data, directed donation should be reserved for cases of true medical necessity.

## TAKE HOME POINTS

- The general-community–donated blood inventory is safer than ever.
- Directed donations have been shown to more frequently test positive for viral infectious disease markers.
- First-time donors are at higher risk of testing positive for viral markers than repeat donors.
- Directed donation carries additional costs which may not be covered by third-party payers.
- Directed donation should be limited to true medical necessity.

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# Not All Acute Lung Injury After a Transfusion Is Transfusion-Related Acute Lung Injury

Melissa R. George, DO and Sprague W. Hazard III, MD

Transfusion-related acute lung injury (TRALI) poses separate and distinct challenges for anesthesiologists and transfusion medicine specialists. However, where one specialty's trials end may be just the beginning for the other specialty. For anesthesiologists, TRALI is a seemingly infrequent complication that pertains solely to the patient being cared; for example, how often in the operating room are we dealing with an endotracheal tube filled with foam? If it happens, you deal with that endotracheal tube and that patient. In contrast, for transfusion medicine professionals, it is a sentinel event that sets off a cascade of steps that must be taken to prevent harm to other potential blood recipients. Several studies have suggested that transfusion reactions are underreported, with an estimated 14% of possible TRALI cases reported to the blood bank by the clinical care team. Failure to report possible TRALI may result in additional subsequent reactions in patients transfused products from potentially implicated donors. In this chapter, we outline the symptoms, pathophysiology, and the proper procedures for reporting TRALI.

In April 2004, an international consensus conference developed the definition of TRALI which is still in use today. TRALI is defined as a new acute lung injury (ALI) characterized by the onset of symptoms within 6 hours of a transfusion—which is a lot more subtle than an endotracheal tube filled with foam. Symptoms include severe hypoxia and dyspnea with evidence of new pulmonary infiltrates radiographically. Recognizing that patients at risk for ALI often receive transfusions, the panel created a two-tiered definition: TRALI and possible TRALI. Possible TRALI is used when there is a clear temporal relationship to an alternative risk factor for ALI, whereas TRALI is ALI that has no temporal relationship to an alternative risk factor for ALI. Pulmonary edema associated with TRALI is noncardiogenic and careful evaluation of fluid intake and output must be initiated to rule out congestive heart failure (CHF) or CHF following transfusion, deemed transfusion-associated circulatory overload (TACO). It can be helpful to compare pre- and posttransfusion chest x-rays; however, the clinical and

radiologic manifestations of TACO and TRALI appear similar. As such, echocardiography and B-type natriuretic peptide may be beneficial in the differential diagnosis between hydrostatic and permeability pulmonary edema. Distinguishing between the two is especially difficult in critically ill patients that commonly have multiple comorbidities as well as disease states that cause an increase in capillary permeability (e.g., sepsis) that can lead to edema. A diagnosis may only be determined by the response (or lack thereof) to therapy such as diuretics. The decision to test donor and recipient blood for immunocompatibility can be made solely on this basis. It is important to recognize that the definition of TRALI is dependent on there being no pre-existent sources of ALI prior to transfusion. The clinical assessment that follows is aimed at uncovering whether or not the new ALI is mechanistically related to the transfusion or if other factors may be to blame.

TRALI often features tachycardia, fever (1° to 2°C increase), cyanosis, and hypotension. Patients with CHF/TACO may also feature new pulmonary infiltrates, but are more likely to have hypertension as a result of increased intravascular volume rather than the hypotension observed with TRALI. The unique pathophysiology of TRALI, as compared to other forms of ALI, has serious implications for donor management. The current hypotheses are that TRALI results from either an antibody-mediated process, mainly that antibodies in the donor's plasma against human leukocyte antigens (HLA) or human neutrophil antigens (HNA) or a two-hit process, where predisposing illness coupled with nonantibody factors (NAFs) initiate respiratory burst. In the first hypothesis, the cause can be investigated with testing for HLA and/or HNA antibodies in the donor and testing the HLA/HNA type of the recipient. If there is an antibody–antigen match, TRALI is the likely cause of the patient's symptoms and the donor should be indefinitely deferred from future blood donation. As women are more likely to form such antibodies during pregnancy, female donors are excluded from plasma donation and parous female apheresis platelet donors much be screened for anti-HLA/HNA antibodies. This process has further limited the availability of already scarce AB plasma. These strategies have mitigated the TRALI risk to some degree, but outliers remain. In the two-hit hypothesis model, it is believed that biologic mediators other than antibodies cause ALI. The first hit is the patient's clinical condition, potentially predisposing to lung injury. Conditions such as sepsis, trauma, malignancy, and postoperative state all may represent this first hit. The second hit would be biologic substances that cause pulmonary endothelial cell activation and neutrophil sequestration. These substances include lipids, cytokines, and endotoxins.

Regardless of the underlying mechanism, all suspected TRALI cases should be reported to the blood bank for further investigation. The transfusion medicine service would much rather investigate cases that end up not being TRALI than missing potential

cases that could put other blood recipients in harm's way. When TRALI is suspected, a transfusion-reaction report should be initiated. Hospital policy should specify the samples that should be collected and sent to the blood bank. In general, this is usually an EDTA tube (lavender top) and a clot activator (red top) for the blood bank to be able to repeat confirmation of ABO/Rh cross-match and a DAT. The specimens are compared to pretransfusion specimens and are visualized for hemolysis. A clerical check is performed to make sure that all identifiers match. Additional specimens may be necessary to fully investigate TRALI. A thorough clinical history, evaluation of intake and output is a critical first step. All blood products given in proximity to the patient developing symptoms must be investigated as a possible causative agent, particularly products with high plasma content. If HLA/HNA antibodies are discovered in a donor, any cocomponents (derived from the same whole blood donation or apheresis donation) are quarantined and generally discarded to protect other patients.

While TRALI is a clinical diagnosis, there are important implications for the transfusion service regarding donor management and the safety of future blood recipients.

## TAKE HOME POINTS

- Not all ALI after transfusion is TRALI.
- There are two hypotheses regarding the pathophysiology of TRALI: antibody-mediated and a nonantibody–mediated "two-hit" hypothesis.
- Suspected TRALI should always be reported to the transfusion medicine service.
- Donors implicated in suspected TRALI cases must be indefinitely deferred to protect other potential recipients.

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# Jehovah's Witnesses and Bloodless Medicine

Melissa R. George, DO and Sprague W. Hazard III, MD

Jehovah's Witnesses (JWs) are a frequent topic of medical ethics discussions. Official JW doctrine, as of 1945, prohibits blood transfusion as a result of interpretation of certain biblical passages such as:

> "For the life of every creature is its blood: its blood is its life. Therefore, I have said to the people of Israel, you shall not eat the blood of any creature, for the life of every creature is its blood. Whoever eats it shall be cut off."
>
> —Leviticus 17:14

In general, JW patients will not accept most common blood components such as whole blood, packed red blood cells (pRBC), plasma, platelets (PLT), or granulocytes, **but it is paramount to recognize that individuals make their own decisions.** Most do not accept autologous blood that was precollected, but may accept intraoperative salvaged blood that was continuously circulating (as it is physically contiguous with one's body) rather than being stored temporarily in a bag. Many will also accept fractionated blood products such as albumin, cryoprecipitate, and blood clotting factors. Receiving a transfusion and being unrepentant could result in being excommunicated from or shunned by the congregation for having broken an essential tenet of the faith. Given the potential for excommunication, some practitioners reaffirm the patient's wishes after any family and clergy has left to ensure that they would truly rather die than receive a blood transfusion. Despite these general statements, it is **essential** to have an in-depth discussion with the individual patient about his or her wishes as part of the consent process and not to make assumptions about the preferences of a JW patient.

As of August 2017, the JW faith includes over 8 million people worldwide, with about 2.5 million of those living in the United States (approximately 0.8% of the US population). This makes it likely for clinicians to encounter JW patients and, as the US population gets older and sicker, these patients will present with complex medical histories and the need for invasive procedures. There is a wealth of information regarding the care of JW patients. Despite this however, there are no established

guidelines, making an understanding of the possible treatment approaches for JW patients necessary. Issues surrounding JW patients, coupled with patient blood management initiatives, have led to the creation of "bloodless medicine" programs at a number of large institutions. While the impetus for bloodless medicine may have developed out of necessity for the care of JW followers, religious reasons are not the only incentive to minimizing transfusion. There is evidence that autologous blood transfusion (ABT) may be a risk factor for adverse outcomes independent of anemia. In addition to the economic burden associated with adverse outcomes, there is a significant cost associated with ABT that includes not only the cost of the blood component but also the cost of the screening, verification, and cataloging which adds (in multitude) to the direct costs.

At present, there are a limited number of studies comparing the outcomes of patients who receive bloodless care with that of a matched control group, so the final "answers" about bloodless perioperative care are not yet with us. However, a majority of the studies suggest that patients receiving bloodless care have similar outcomes to patients that are amenable to ABT. A recent study of cardiac surgery patients showed a lower incidence of myocardial infarction reoperation for bleeding in the bloodless-care group as well as the duration of mechanical ventilation, ICU care, and total hospital stay as well as 1-year survival. The bloodless medicine strategies employed at various institutions are not standardized, unfortunately. However, virtually all bloodless approaches seek to reduce risks, improve outcomes, and decrease costs for all patients. To do this, preoperative, intraoperative (anesthesia and surgery techniques), and postoperative planning is imperative.

## Preoperative Strategies for a Bloodless Perioperative Clinical Course

Patients eligible for bloodless medicine should be identified at least 1 month in advance of a surgical procedure to allow time for preoperative planning. The first step is to identify, assess, and treat pre-existing anemia and to optimize erythropoiesis. In the case of iron deficiency, meeting with a dietician, iron supplementation (oral or intravenous), and vitamin C to aid iron absorption all may be advised. Unmanaged anemia is a contraindication for elective surgery and surgery should be scheduled at a time when hemoglobin has been optimized. Another element of preoperative planning is to minimize blood loss by obtaining a thorough history regarding bleeding risk. A careful review of medications is essential, particularly anti-PLT agents and anticoagulants. Limiting alcohol and stopping or altering the dose of certain medications and supplements can contribute to balanced coagulation and PLT function. The addition of medications and supplements such as antifibrinolytics (aminocaproic acid or tranexamic

acid), desmopressin, erythropoietin, vasopressin, or vitamin K may be employed to treat bleeding, increase coagulation factors, and optimize endothelial function. Less frequently, iInterleukin-11 and G-CSF have been used to support PLT and white cell counts, respectively.

## Intraoperative Strategies for a Bloodless Perioperative Clinical Course

Intraoperative planning places great focus on minimizing blood loss through the use of blood-sparing techniques, strict maintenance of hemostasis, and avoidance of coagulopathy, mainly through specific anesthesiology and surgical techniques.

## Anesthesiology Techniques

Optimizing cardiac output, ventilation, and oxygenation are key elements of intraoperative patient blood management. In order to limit or avoid transfusion, aggressive use of volume expanders or intravenous fluids may be employed. Depending on the setting, crystalloids or colloids may be appropriate. Many JW patients accept autologous blood collected by cell saver/intraoperative cell salvage as it is generally viewed as an extension of the circulatory system. Techniques to reduce blood loss such as employing intraoperative hypotension or hypothermia may be implemented. Acute normovolemic hemodilution (ANH) techniques include the phlebotomy of two to four units of whole blood prior to a procedure where excessive blood loss is expected. This volume is replaced with either colloid or crystalloid which lowers the hemoglobin/hematocrit of exsanguinated blood. The patient's own blood is then reinfused at a time in the procedure when the bleeding has slowed or stopped. Some JW patients will not accept ANH as blood is stored extracorporeally and is not continuously circulated during the procedure and this needs to be discussed on an individual basis.

## Surgical Techniques

A number of surgical technologies are considered blood sparing. Several are listed below:

**Electrocautery:** Burns and seals blood vessels.

**Cryosurgery:** Freezing cancerous or abnormal tissue using liquid nitrogen to cut off the blood supply and remove the tissue.

**Laser surgery:** Targeted laser beams to precisely cut or destroy tissue with minimal damage to surrounding structures.

**Gamma Knife:** Noninvasive brain surgery involving delivery of precise radiation dose.

**Special scalpels, such as ultrasonic and microwave coagulating:**Uses ultrasound waves or microwave energy to cut tissue and seal blood vessels.

**Robotic-assisted surgery:** Minimally invasive techniques where the surgeon uses robotic arms to assist in intricate procedures, especially in smaller, anatomically enclosed areas.

**Topical hemostatic agents and sealants:** Adjuncts to standard surgical techniques and electrocautery. They include materials that activate PLTs and the extrinsic pathway and provides a scaffold for thrombus. Some absorb water and concentrates hemostatic factors at the site of bleeding or physically tamponades bleeding vessels. This group also includes biologically active agents that can enhance hemostasis such as thrombin and fibrin.

All of these techniques minimize damage to blood vessels to better control mechanical sources of bleeding.

## Postoperative Strategies for a Bloodless Perioperative Clinical Course

Postoperative planning centers around maintaining the gains achieved during the previous stages of patient blood management. Managing anemia and continued optimization of erythropoiesis are important, as is managing bleeding, maintaining hemostasis and coagulation, and being alert to possible adverse effects of medication that could contribute to anemia. Recognizing and managing postoperative infections is also critical to avoiding anemia.

While JWs are the most recognizable proponents of bloodless medicine, the concepts and techniques are achieving greater acceptance as part of patient blood management programs to reduce transfusion risks, be better stewards of an often-scarce resources, and decrease healthcare costs.

### TAKE HOME POINTS

- Bloodless medicine programs were created largely to meet the needs of JW patients who refuse transfusion for religious reasons.
- Non-JW patients are showing increased interest in bloodless medicine.
- Bloodless medicine programs implement multimodal strategies to optimize hemoglobin and hemostasis prior to surgery, and limit blood loss before, during, and after medical interventions.
- Advance planning is necessary.
- Do not hesitate to consult your institution's ethics and legal departments if you feel yourself on uncertain ground with respect to any bloodless surgery or transfusion

issues, regardless of whether they are a practicing JW.

- Outcomes data have shown length of stay, complications, cost of care to be equal or better than patients willing to receive ABT.

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# The Ethics of Jehovah's Witnesses and Transfusion

Rose Christopherson, MD PhD (Retired)

The issues surrounding transfusion of Jehovah's Witnesses should be examined in the broader context of medical ethics. Two aspects of medical ethics are important in this discussion: informed consent, and Do Not Resuscitate (DNR) orders. Patients are normally informed about their treatment plans. They have the right to refuse any care, as long as they are both competent and have the capacity to make health care decisions. Many Jehovah's Witnesses refuse transfusion of blood or some blood products because of their interpretation of certain passages in the Bible. Because other patients have the same right to refuse blood transfusion, it is not appropriate to argue with patients about their reasons for refusal. If they are competent, they have the right to refuse.

It is important to determine whether the patient is competent and has the capacity to make medical decisions, and to determine exactly what the patient refuses. Some patients are willing to accept reinfusion of their own blood, or transfusion of some blood components such as fresh–frozen plasma. Jehovah's Witnesses are as diverse a group as any other religious group. It is wrong to assume from the fact that a patient is a Jehovah's Witness that she or he refuses blood transfusion. It is also important that there is no coercion of the patient, intended or unintended, because of the presence of family members or clergy. This is best done by speaking with the patient alone. It is important, in obtaining informed consent, to make it very clear that patients do not necessarily die as a result of withholding of transfusion. They may have strokes, myocardial infarction, or other organ damage. Thus the patient needs to understand that, if transfusion is withheld, she or he may emerge from the anesthetic with permanent impairment.

All participating caregivers must understand the patient's wishes and agree to the same plan. Surgeons have been known to refuse to perform surgery on patients who refuse transfusion. The type of surgery to be performed, urgency of the surgery, and likelihood of blood loss are all important.

Participating nurses must agree with the plan. Even though the anesthesiologist will give or withhold blood products, if the patient dies or has some other adverse outcome

related to anemia, all on the care team will share the pain of this bad, and in a sense avoidable, outcome.

Often, DNR orders are suspended in the perioperative period. Transfusion of blood or blood products is often part of resuscitation. DNR orders are on most patients' charts because of some terminal disease the patient has. When these patients need surgery for palliation or for some unrelated problem, they are generally willing to have their DNR orders cancelled for the perioperative period. They may need airway management or administration of resuscitation medicines to maintain appropriate vital signs during surgery. Their DNR status will resume after surgery.

Jehovah's Witnesses, on the other hand, are often quite healthy, and they may want every form of resuscitation other than blood transfusion. The situation can be even more troubling if the Jehovah's Witness wants transfusion withheld from a child or an elderly parent. Thus the refusal of a Jehovah's Witness, or of any other patient, of perioperative transfusion is somewhat contrary to accepted hospital procedures related to perioperative resuscitation.

It is not surprising if anesthesiologists feel uncomfortable about caring for Jehovah's Witnesses. We are asked to agree to things that we do not otherwise agree to. We are asked, potentially, to allow a patient to bleed to death while withholding the red cells, platelets, or fresh–frozen plasma that would deliver oxygen to their tissues or even help stop the bleeding. Physicians or other caregivers may feel that they are asked to compromise their own religious or other deeply held moral beliefs. In fact, this is true. The patient's wishes have some priority over the physician's wishes, simply because treating patients against their will is battery and is not permitted.

However, it is not clear that a caregiver who refuses to anesthetize a patient because of the patient's unwillingness to receive blood is necessarily doing wrong. In some cases it is obvious that the patient is very unlikely to survive a procedure without transfusion. If at all possible, the caregiver should find another anesthetist, who is willing to agree to the patient's wishes. Lists of colleagues who are willing to withhold transfusion are helpful. It is never possible to avoid this conflict completely. Sometimes anesthesiologists will have to decide whether their duty to give the anesthetic and do their best to keep patients in good condition without transfusion outweighs their personal religious or moral beliefs.

Finally, we turn to patients who cannot make health care decisions. This includes unconscious patients, incompetent patients, and children. Some of these patients may have a document stating what interventions may be made on their behalf, for example, a living will. Some Jehovah's Witnesses may carry a wallet card, which may state that they refuse blood. However, if such documentation cannot be found, given the diversity of beliefs among Jehovah's Witnesses, it should be assumed that transfusion is

permissible. In the case of children, there is legal controversy (www.virtualmentor.org). If surgery is elective, it is probably best to obtain consultation from both an ethics committee and a hospital attorney.

## Management Strategies for Jehovah's Witness Patients —The Basic Three-Part Approach

1) **Minimize losses**

- Consider staging complex procedures so that time between operations can allow some recovery for patients
- Apply damage control surgery principles to minimize bleeding as a first objective, then return later for definitive treatment
- Minimize blood draws
- Avoid anticoagulants and antiplatelet agents as much as possible
- Consider recombinant Factor VIIa to decrease the need for further transfusions and improve hemostasis
- Employ the use of hemostatic surgical devices like electrocautery, ultrasonic scalpels, and tourniquets
- Utilize pharmacologic agents such as fibrin glues as blood vessel sealants and antifibrinolytics
- Consider using strategies such as normovolemic hemodilution, controlled hypotension, and continuous recovery cell salvage devices

2) **Increase production**

- For planned elective cases, use recombinant human erythropoietin to improve reticulocytosis and increase normoblast production
- Supplement with IV iron, folate, and vitamin B12

3) **Stabilization and substitutions**

- When bleeding is suspected, take decisive interventional steps early to quickly control blood loss
- Supplement oxygen and resuscitate fluid losses aggressively to improve oxygen delivery
- Manage coagulopathies early
- In select cases, consider blood substitutes such as PolyHeme and Hemospan (still in clinical trials)

### TAKE HOME POINTS

- The issues involved in the care of Jehovah's Witness patients are rooted in the medical ethics problems of informed consent and DNR orders.
- Do not argue with a Jehovah's Witness patient about his or her reasons for refusal of blood or blood products.
- Jehovah's Witnesses are as diverse a group as any other religious group. It is wrong

to assume from the fact that a patient is a Jehovah's Witness that she or he refuses blood transfusion.

- Always speak to the Jehovah's Witness in a confidential location.
- Accept that there may be varying levels of discomfort among the anesthesia and operating room teams. It is never possible to avoid this conflict.
- Unconscious, incompetent, and pediatric Jehovah's Witness patients are a special situation—consult the ethics and legal staff.

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## SECTION V

# MEDICATIONS

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# Introduction

Wayne T. Nicholson, MD PharmD

In anesthesia practice, physiology and pharmacology is your bread and butter. While you often don't have control of the physiology and pathology you are often presented with, you do have a "relative" control over the medications that are administered. Relative in the sense of not always having complete control of the outcome once the drug is administered. In 1994, it was estimated that 106,000 deaths per year in the hospitals in the United States were due to adverse drug reactions (Lazarou et al.). These estimated deaths are attributed to the correct use of pharmaceuticals that resulted in these poor outcomes.

Adverse drug reactions are not the only way drugs can result in mortality. Medical errors with pharmaceuticals can also occur (wrong drug, dose, administration, etc.). In 2013, it was estimated that 251,454 deaths in the United States were attributable to medical error (Makary et al.). While not all medical error is due to pharmaceuticals, it is a significant component. Considering the size of these poor outcomes, if taken together, medication use would likely be the third leading cause of death in the United States following heart disease and cancer. Unfortunately, the deaths due to medications are nowhere to be found on the Centers for Disease Control list of the top 10 leading causes of death in the United States. While these estimates certainly can be debated, there is little debate about problems and poor outcomes that can result with the use of pharmaceuticals.

Medication problems come in two main types, anticipated and unanticipated. Unanticipated reactions are often the result of hypersensitivity, where anticipated adverse reactions are known to the practitioner. Cefazolin can provide a good example of both. If a patient with no known medication allergies receives cefazolin and has an anaphylactic reaction, this would be unanticipated adverse drug reaction. However if a patient receives cefazolin, has an anaphylactic reaction wearing an allergy band that lists cephalosporins as an allergy, this would be anticipated and in this case be a medical error.

Not all anticipated adverse reactions are due to medical errors as in the case above. Many adverse reactions are known and dealt with as regular part of clinical practice.

Hydromorphone-induced respiratory depression is well known. While this is a known risk, proper use of the drug considering not only the pharmacodynamics of the drug, but the patient (age, weight, pathology, etc.), and the pharmacokinetics of the drug (absorption, distribution, metabolism, and excretion) decreases the risk of hydromorphone use to the patient.

One main method of defense in preventing these anticipated adverse effects is education. Knowing which drug to use and how it works clearly is important. However, knowledge about what can go wrong with a drug and how to fix a problem caused by the drug is equally if not greater in importance. The cases in this section provided by clinicians contain many pearls in anesthesia pharmacology to assist you. While the physiology you're presented with might be less than ideal, anticipation of medication issues before administration may be the best control you have in preventing a poor patient outcome.

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# What Just Happened! What You Need to Know About Medication Errors

Raymond G. Graber, MD and Chad T. Dean, MD

You have come in to set up for your case for the day. You are a little tired, having been up all night 2 days preceding, You also arrive a little late, and are hustling to get set up on time. (After all, you are working with Dr Marcucci, and she is a stickler for starting on time!) The patient is induced and while you are mask ventilating the patient, you watch the heart rate progressively slow down to asystole. What just happened! This can't be right! In this chapter, we will discuss the issue of medication errors. We will discuss how common they are, what types of errors occur, why they occur, and how they can be prevented.

## Introduction

"Anesthesia is the only area where medications are typically prescribed, prepared, administered, and recorded by a single individual (an anesthesiologist or anesthetist) without any other health professional to check or monitor the process." Given that many of the drugs that we administer are high risk, the potential threat to patients is obvious.

For a drug to be administered correctly, the correct drug must be given to the correct patient, in the right dosage and concentration, via the correct route, at the correct time. It also must be documented correctly. This leads to the following definitions:

- Drug error—inappropriate drug, dose, concentration, label, time, route, or patient.
- Adverse drug reaction–noxious unintended reaction which occurs after appropriate dosing and administration.
- Adverse drug event—injury resulting from medical intervention related to a drug (includes both drug errors and adverse drug reactions).

## Are Medication Errors a Problem in Anesthesia?

In 1978, JB Cooper published a landmark paper that analyzed critical incidents that occurred during anesthesia—he wanted to determine the causes and contributing factors.

A critical incident was defined as an incident that lead to an undesirable outcome or was a "near miss." Drug administration errors were one of the top three causes of all critical incidents, and were responsible for 19% of incidents. So what would your guess be as to what percentage of anesthesiologists would admit to harming a patient with a medication error? To answer this, a survey was conducted in 1995 in New Zealand. The answer: 12.5% of responding anesthesiologists reported having harmed patients by a drug administration error.

## How Common Are Medication Errors in Anesthesia?

The rate of medication error depends on how compulsively you define a medication error and who is doing the observing/reporting. Three different prospective studies in South Africa, Seattle, and New Zealand reported incidences of self-reported drug administration errors (per patient) of 0.36%, 0.68%, and 0.75%, respectively. So, by this data, if you do 4 cases a day, 5 days/wk, 46 wks/yr (about 920 cases), you will have an estimated 3 to 7 drug errors per year. In 2016, Nanji et al. conducted a study where trained observers watched all phases of medication preparation, delivery, and documentation. They used much stricter definitions of proper technique (e.g., complete labeling and initialing of all syringes, timely charting, and timely response to hemodynamic changes). They observed an error rate of 4% of all drug administrations. Although 20.9% of the errors had little potential for harm, 33.3% led to an observed adverse drug event and an additional 45.8% had the potential for patient harm. Sobering data!

## How Do We Identify Our Drugs?

The proper way to identify a drug is to read the name on the vial, syringe, or infusion bag. However, there are also secondary cues (that we all commonly use), that can lead to errors. For example, the size and shape of the syringe or vial, the location of the syringe or vial, and the color coding of labels, vial tops, etc. So for example, being creatures of habit, we draw up our drugs in certain syringe sizes, and lay them out in a specific way. I know I put my ephedrine in a 10-mL syringe, and put it at a certain location in my setup. When I need that syringe, I know just where to grab it. What happens if someone gives you a break, and moves the syringe around? Will you always check the label to make sure you have grabbed the right syringe?

## What Is the Proper Technique to Draw Up and Administer a Drug?

When you are preparing to draw up a drug, read the vial name first. If your syringe has a

label on it, compare the label of the syringe to the label of the vial. If the syringe is not yet labeled, immediately put a label on it before moving on to the next med.

When you are preparing to administer a drug, make sure you know what the drug does, what the normal dose range is, what the patient's allergies are, and what the potential side effects are. Pick up the syringe, read the label. Identify the proper injection port. Alcohol wipe the injection port. Read the label (again!) as you are attaching the syringe to the injection port. Know how fast you can administer the drug. Inject. Read the label again. We know this sounds redundant, but it gives you one last chance to stop the delivery of the medication!

## What Medication Issues Predispose to Medication Errors?

- Look-alike packaging and labeling. (A glass vial with a white top looks like another glass vial with a white top!)
- Look-alike names (e.g., Brevital/Brevibloc, epinephrine/ephedrine, dobutamine/dopamine).
- Supplier change can lead to vials with a different look. We have seen this inadvertently lead to look-alike drugs, when previously this was not an issue.
- There are also proximity issues where drugs are stored adjacent to each other. It is possible for similar-looking drugs to be stored next to each other, and even for a vial to wind up in the wrong storage slot.
- Varying concentrations. We have multiple drugs that come in different concentrations. Ketamine comes as 10 mg/mL, 50 mg/mL, and 100 mg/mL. Epinephrine can be drawn from an infusion bag (at our place—16 mcg/mL), or a 1-mg vial may be diluted out to 10 mL (100 mcg/mL), and we have seen concentrated epi 1 mg/mL l mg in a 10-mL syringe. Local anesthetics come in different concentrations. Hospitals sometimes have different infusion formulations of the same drug, for example, "standard" epinephrine infusion and "concentrated" epinephrine infusion. Heparin is another drug that has multiple concentrations available. Heparin concentration errors have been implicated in the deaths of newborn babies—when concentrated heparin was administered rather than heparin "flush."

## What Environmental and Practitioner Issues Predispose to Medication Errors?

**Environmental issues:** Poor lighting can make it hard to identify meds. Noisy environments can lead to communication issues. Residents tend to stand in their rooms and talk to each other in the mornings as the call team leaves and the next team comes in. This type of distraction can lead to errors.

**Practitioner issues:** Fatigued practitioners can be inattentive and make mistakes. We administer a ton of different drugs during the course of our careers. If you don't fully understand the proper use, dosing, and potential adverse consequences of a drug that you administer, you can run into problems. If you don't have full knowledge of a patient's history and allergies, you may administer a drug that is inappropriate for that patient.

**The need for speed and repetition errors:** It is not unusual in a big or long case to draw up dozens of vials of drugs. We have even been in cases involving prolonged cardiac arrest in the OR that involved hundreds of syringes being drawn by the attending and two residents during a code that lasted for an hour.

## Types of Errors

Drug errors have been classified into the following types:

- Substitution (wrong label): A drug was drawn from the wrong vial or infusion bag, thus an incorrect label is on the syringe.
- Substitution (wrong syringe/bag): The syringe or infusion is labeled correctly, but the label wasn't read properly and the wrong syringe or infusion is used for an administration.
- Wrong dose.
- Failure to administer properly.
- Wrong route.
- Wrong choice of drug.
- Omission: Drug not given.
- Repetition: Extra dose of an intended drug.
- Violations of good practice.

When we looked at our data, the most common issues were wrong syringe 31%, wrong dose 26%, wrong label 12%, wrong route 12%, and wrong drug choice 10%.

## ASA Closed Claims

When the ASA Closed Claims Database were reviewed for medication errors, the most common drug involved was succinylcholine. There were 12 cases of awareness, due to succinylcholine boluses given prior to induction agents, or succinylcholine infusions that were started inadvertently in awake patients. There were also five cases of administration to patients with a history of definite or probable pseudocholinesterase deficiency, resulting in prolonged neuromuscular blockade. In addition, hyperkalemic cardiac arrest occurred in two paraplegic patients and a patient with Guillain–Barré syndrome.

Another problematic drug was epinephrine. Epinephrine errors were particularly dangerous, with death or major morbidity resulting in 11 of the 17 epinephrine-related cases. Six of the 17 cases involving epinephrine were caused by ampoule swaps where epinephrine ampoules were confused with ampoules of the intended drugs. These drugs that were interchanged with epinephrine included ephedrine, pitocin, and hydralazine.

## Case Examples

We will now review some cases where medication errors occurred. These are all real cases (with slight modifications). Some of these cases are older, and reflect drug vials and drug trays from that time. Let's see what we can learn from these cases.

**Case 1:** An 82-year-old female with coronary artery disease and hypertension presented for aortobifem bypass graft. General anesthesia was induced with fentanyl 100 mcg, etomidate 6 mg, and succinylcholine 100 mg. There was a rapid decline in the BP and heart rate (HR). The patient became asystolic. The patient was initially treated with phenylephrine 400 mcg in increments as the BP dropped, but then was given ephedrine 50 mg and epinephrine 160 mcg. Once the patient became asystolic, CPR was initiated, the patient was intubated, and epinephrine 1 mg was administered. After 30 to 40 seconds, she regained sinus rhythm and became hypertensive. **What was the drug error?**

**Answer:** During the setup, the resident had drawn up esmolol instead of etomidate. At that time, each drug came in a 10-mL glass vial. This vial of esmolol was meant for making up infusions, so had a concentration of 250 mg/mL. This means that the patient was induced with 750 mg of esmolol. So this was a substitution error—wrong label. Contributing factors: look-alike vials, inattention.

**Case 2:** A 21-year-old female presented for C-section under epidural around 1:00 AM. After delivery of the baby, 1-g cefazolin was administered, along with 20 units of pitocin (which was added to the IV bag). Soon after, the patient complained of feeling short of breath. She quickly progressed to apnea. She was bag and mask ventilated, induced, and intubated after pentothal 300 mg and succinylcholine 100 mg. At the end of the case, she was reversed and extubated. **What was the drug error?**

**Answer:** This was a cefazolin–vecuronium swap. Both vials were similar-looking vials with white caps. The resident grabbed the wrong vial and drew it up. Although the patient had no physical adverse effects, she did suffer awareness of these events—she was initially awake and paralyzed. So this was a substitution error—wrong label.

Predisposing factors: look-alike vials stored close together, fatigue, and inattention.

**Case 3:** A 35-year-old male presented for lumbar discectomy. The patient was administered 2-mg midazolam in preop hold just immediately prior to moving to the OR. On arrival to the OR, the patient was more than just sedated, he was apneic. The patient was quickly mask ventilated and intubated. **What was the drug error?**

**Answer:** This was a midazolam–rocuronium swap. The resident had drawn up rocuronium into a syringe labelled midazolam—so the patient was administered 20-mg rocuronium just prior to transport to the OR. This was a substitution error—wrong label.

**Case 4:** A 23-year-old female presented for C-section via epidural anesthesia. After delivery of the baby, the HR dropped to 50, and BP was 84/38. She was given atropine 0.8 mg (with little improvement), then ephedrine 10 mg. The patient became apneic, BP was not measurable, and there was no palpable pulse. EKG showed a wide complex bradycardia. She was intubated, chest compressions were initiated, and epi 500 mcg was given. The BP immediately recovered. However, at the end of the case, she did not awaken immediately, and was taken intubated to the SICU. In the SICU, she was initially encephalopathic, but recovered over a 2-day period. She eventually went home fully intact. **What was the drug error?**

**Answer:** This was an ephedrine–succinylcholine drug swap. The patient was hypotensive and bradycardiac, and was given 20-mg succinylcholine instead of the planned 10-mg ephedrine. The error type here was a substitution error—wrong syringe. The predisposing factors: two 10-mL syringes lying side by side on the back table, fatigue, and inattention.

**Case 5:** A 50-year-old female underwent an uneventful general anesthetic for a cervical spine discectomy and fusion. At the end of the case, she was reversed and extubated. In the PACU, her HR progressively dropped over 45 minutes, then she became asystolic. After brief chest compressions, EKG complexes returned, with a HR in the 40s. She was given atropine, then monitored for a few hours in the PACU. **What was the drug error?**

**Answer:** This was a glycopyrrolate under dose. She had received 0.5 mg glycopyrrolate with neostigmine 5.0 mg, and this was an inadequate dose to counter the HR-lowering effect of neostigmine. Error type—wrong dose.

Other examples of wrong dose errors: pump programming errors, wrong-weight–

based calculations in kids, wrong doses given secondary due to lack of knowledge. You could make the argument that many cases of awareness under anesthesia are secondary to underdosing of the anesthetic.

**Case 6:** A 60-year-old male presented for CABG. There was an uneventful intraoperative course. The patient was extubated 4 hours postop. The next morning, a nurse flushed an IV line that had been capped in the OR prior to transport. A few minutes later, the patient becomes apneic. The SICU team bag and mask ventilated, then reintubated the patient. Several hours later, the patient was extubated again. **What was the drug error?**

**Answer:** The patient was administered a rocuronium drip in the OR. At the end of the case, the drip had been disconnected and the IV tubing had been capped at the end of extension tubing. However, the line had not been flushed. When the IV was flushed the next day, residual rocuronium in the line was flushed into the patient. So, the error here was failure to properly administer a drug.

There are a variety of variations on this theme of improper medication administration. We discussed failure to flush in the above example. You can also administer some drugs too fast. These errors occur when practitioners push drugs that should be given by infusion or when pumps are programmed with the wrong rate. So, for example, we have seen cardiac arrest due to potassium pump error and managed hypoglycemia after insulin drip error. And of course, we have treated the red man syndrome after vancomycin bolus. Another issue is administering drugs at the wrong time. A prime example of this is perioperative antibiotics. We know they are most effective when given in the hour prior to incision. So if they are given too early or too late, they are less effective, and the rate of perioperative wound infection increases. Antibiotics also have to be redosed on a schedule to maintain adequate blood levels.

**Case 7:** You are called to evaluate a patient who had an epidural placed for labor. It does not appear to be working well. You check the epidural infusion (a dilute bupivacaine/fentanyl mix) and discover that it is actually hooked up to the peripheral IV. What was the drug error?

**Answer:** Obviously, the error here is medication administered at the wrong site. We have seen epidural infusions being given peripherally and have heard of multiple drugs being given epidurally, including magnesium, pentothal, vecuronium, succinylcholine, epinephrine, and pitocin. In an effort to combat these types of errors, many centers have tried to change the system to prevent further errors. For example, we now use portless, yellow-striped tubing to administer epidural and nerve block infusions. In addition,

many centers use a different type of pump for epidural infusions, where it was once standard practice to use IV pumps for epidural infusions, too.

**Case 8:** You administer cefazolin to a patient prior to incision. They become acutely flushed, hypotensive, and develop bronchospasm. You look back at the chart and discover that the patient is allergic to cephalosporins. **What was the drug error?**

**Answer:** This case is an example of a wrong drug choice error. Besides giving patients medications that they are allergic too, another example would be administering succinylcholine to a patient with known pseudocholinesterase deficiency, or triggering agents to a patient with malignant hyperthermia. These type of errors occur either because of inadequate history taking, inadequate knowledge, or just fatigue.

**Case 9:** You draw up 20 mL of propofol out of a 100-mL bottle of propofol. You re-enter it after induction and draw up 20 mL more. You now have 60 mL left, and decide to save it for the next patient. Why not? Let's try to save the hospital some money! **Is there an error here?**

**Answer:** This is a violation of safe practice. In fact, there have been multiple cases of hepatitis B and C traced back to reusing vials or syringes that had been inadvertently contaminated. For example, in 2002, the Oklahoma State Department of Health investigated a cluster of hepatitis C virus (HCV) infections, and traced them back to a pain clinic. It was discovered that a practitioner reused needles and syringes routinely during clinic sessions. A single needle and syringe was used to administer each of three sedation medications (midazolam, fentanyl, and propofol) to up to 24 sequentially treated patients at each clinic session. Eventually 100 cases of hepatitis were traced back to this clinic. Since 2001, more than 150,000 patients in the United States have been notified of potential exposure to hepatitis B virus (HBV), HCV, and HIV due to lapses in basic infection control practices. In response to this, the Center for Disease Control initiated a public health campaign ("The One & Only Campaign"), to raise awareness among patients and healthcare providers about safe injection practices. Now, most of us would cringe at the above practice, and pat ourselves on the back for using safe injection procedures. But how about this—do you religiously always alcohol wipe an injection port prior to use?

## How Can We Reduce the Incidence of Medication Errors?

There have been a variety of strategies recommended to try to reduce the incidence of medication errors. A lot of these are based on expert opinion, and not on randomized

controlled trials. Let's take a look at some of these recommendations.

**Medication safety training:** Any department that trains anesthesiology residents, anesthesia assistants, or CRNA students should have some type of formal education on proper drug administration and avoidance of medication errors.

**Syringes are labeled:** This is a common sense thing—all syringes and infusions should be labelled. The one exclusion would be if you draw up a drug into a syringe and immediately administer it, but keep in mind that there are institutions and individual anesthesiologists who hold the view that this practice is not rigorous enough. A proper label includes the drug name, concentration, and units. If you see an unlabeled syringe of fluid lying around, discard it. This is also a JCAHO (The Joint Commission) thing. When they inspect an operating room, they will look to see that all syringes are labeled. People tend to be lazy about labeling propofol, thinking it's the only drug that looks like milk. You still have to label it, because it is the right thing to do. But we also have clevidipine now, which is identical in appearance.

**Read the label:** When it comes down to it, the most important recommendation is to compulsively always read the label of every syringe, vial, and infusion. Get in the habit of doing double checks—look at a syringe when you pick it up, and one more time when you are getting ready to inject.

**Drugs should be presented in prefilled syringes when possible:** Many anesthetic drugs are available for purchase in pre-drawn up, nicely labeled syringes. This supply thus avoids the whole issue of improper labeling of syringes and saves some setup time for the anesthesia provider. The downside is increased cost.

**Syringe labels should be color coded by group per international standards:** Syringe labels are typically grouped by color. For example, blue labels are used to indicate opioids; fluorescent red, neuromuscular blockers; yellow, induction agents; orange, tranquilizers; violet, vasopressors; and green for anticholinergics. This allows you to rapidly narrow down the possible syringes when you are looking for a specific drug on your table top. The downside to this is that it is still possible to administer the wrong drug if you don't read the label properly, but it will be a drug in the same group. Also, many errors occur because the practitioner does not see or read the label at all, but just grabs the appropriate-sized syringe—these will not be reduced.

**Consistent trays:** Ideally, the drug storage setup should be as consistent as possible within an operating room. Consistency makes it easier to find meds when you are preparing for a case. However, don't let this consistency lead to complacency—you still need to always read the label of vials—vials can be misfiled.

**Removal of dangerous drugs:** There are some drugs and fluids that probably don't need to be stored at every OR location. For example, epinephrine 30-mL vials, potassium chloride vials, liter bags of sterile water, nonunit-dose cetacaine spray, etc.

were once available in all our OR locations and have now been removed.

**Labels should be checked with a second person before a drug is drawn up or administered:** This recommendation was made by Jensen in 2004. Although this would help prevent substitution errors, routine use for all anesthetic drug preparation would have severe impact on our work flow. An alternative is barcode scanning. Many centers use drug-dispensing cabinets in the ORs—typically a patient is selected, then each drug vial is scanned so that the patient can be charged and so the pharmacy can keep track of the inventory. As you scan your drugs, check the drug name that pops up.

**Neuromuscular blocker issues:** Neuromuscular blocking drugs are particularly dangerous when administered in error. There are a couple of strategies that have been used to try to reduce these errors. For example, manufacturers now routinely put a warning message on the vial caps. Some centers have put shrink wrap warning labels on vials, as an extra layer of security. Another hospital-wide strategy is to limit locations where muscle relaxants are kept. While they need to be stocked in the ORs, ICUs, and emergency department, they probably don't need to be kept in the regular pharmacy stock on a medical floor.

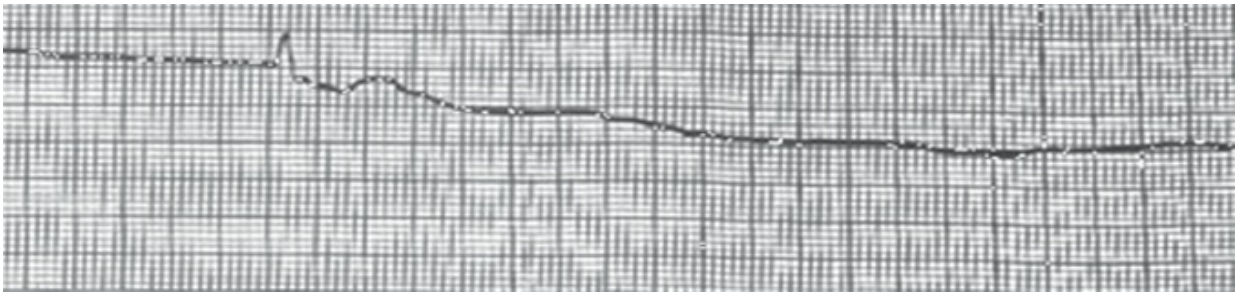
**Manufacturing issues:** Drug manufacturers have come up with different packaging methods to try to reduce medication errors. Heparin now comes in different syringe and packaging systems to reduce the risk of confusing heparin flush with more concentrated heparin. Esmolol for infusion now comes in premixed bags rather than in 2,500-mg vials.

**Review of drug errors in quality improvement meetings/morbidity and mortality conference:** When medication errors occur, they should be discussed at department-wide meetings so that the event can be an educational experience for all. In addition, there should be time spent focusing on what system issues may have contributed to the event. (For example, the presence of injection ports in epidural infusion tubing was an invitation to plugging in piggyback solutions.) If a system issue can be identified, then changing the system may help prevent future medication errors. (For example, switching to portless epidural tubing.)

**Advances in technology:** Many infusion pumps have drug libraries built into them now, with upper and lower infusion limits programmed in. Some researchers have advocated the use of barcode scanning at the time of syringe preparation to produce correct syringe labels, and barcode scanning prior to medication administration to reduce wrong syringe (substitution) errors. Resources such as the internet and phone/tablet apps provide more easily accessed information on drug dosing, metabolism, and side effects.

## Conclusion

Be compulsive in your medication preparation and injection practices. Don't let your day start off like this:



## TAKE HOME POINTS

- For a drug to be administered correctly, the correct drug must be given to the correct patient, in the right dosage and concentration, via the correct route, at the correct time.
- One of the prime features of our job is to give powerful and dangerous drugs in a safe and precise fashion. That's what we do. Unfortunately, we all commit medication administration errors during the course of our careers. The goal is to reduce the incidence and severity of these errors by learning proper drawing up and administration technique and being compulsive about it.
- Some of the most common etiologies of drug errors include grabbing the wrong syringe, labeling a syringe with the wrong drug name, and giving the wrong dose (by bolus or by misprogramming a pump).
- When a medication error occurs, try to evaluate why it occurred, and see if there are system issues that contributed, which may be amenable to change.

## Suggested Readings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# Make Sure You Understand the Complex Medical and Legal Issues Surrounding Off-Label Drug Use

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Imagine this scene: your healthy, 5-year-old patient has just emerged from anesthesia after a routine, 30-minute case for PE tube placement. She is ventilating spontaneously and her vital signs are stable. As you leave the operating room (OR), she becomes agitated, screaming and thrashing on the stretcher, and inconsolable. Pondering your options for treating her emergence delirium, you acknowledge that she does not have an intravenous (IV) line. Quickly, you administer 1 mcg/kg of intranasal dexmedetomidine. She becomes calm and quiet and you are thankful she is no longer a risk to herself. Her parents are reassured, the postanesthesia care unit (PACU) nurses are able to care for their new patient efficiently, and you move on to your next case without interruption. This was a successful and safe intervention, wasn't it? Perhaps so, but intranasal dexmedetomidine use is not described in the U.S. Food and Drug Administration (FDA) package insert.

The practice of anesthesiology reflects a mastery of pharmacology. It is critical that the anesthesia provider understand the proper indication for and administration route of a particular drug, but also has the ability to coadminister agents or even to use them in novel ways. The most responsible and safest approach is to read and understand FDA-approved drug labels and then strive to apply those guidelines to clinical practice. When a drug is used beyond those conditions described on its label, it is considered off-label by the FDA.

The FDA regulates all aspects of drug development, research, safety, marketing, and labeling. The information contained within a drug label summarizes the indications, dosing, and age limitations for medications based on clinical trial data. Therefore, in order to achieve approval for specific uses of a drug, there must be evidence-based data to support it. Obviously, anesthesiologists cannot anticipate every detail of our patient

population. Based on the medical literature, drugs are frequently used beyond the specific guidelines listed in the drug label for dose, route, indication, regimen, or patient population. How common is this practice? Sources cite up to 23% of prescriptions being written for off-label use. In pediatric anesthesia, it is estimated that off-label use of medications occurred in over 70% of administered anesthetics. This trend is not necessarily harmful, but rather, reflects a lack of well-controlled study data held by the FDA (the study has not been done or there is no financial incentive to develop new indications, such as isobaric spinal bupivacaine). Further, if there is a known adverse effect of an off-label drug use, it will be listed in the Contraindications, Warnings, or Precautions section of the label.

According to the FDA, "once a product has been approved for marketing, a physician may prescribe it for uses in treatment regimens or patient populations that are not included in approved labeling. Valid new uses for drugs already on the market are often first discovered through serendipitous observations and therapeutic interventions." It is important to realize that the FDA does not seek to restrict a physician's decision to use a drug off-label and the Physicians' Desk Reference (PDR) also acknowledges this use. Interestingly, the publisher of the PDR, Medical Economics, also publishes an "off-label treatment guide." So, there is acknowledgement that this use has an important place in patient care. Currently in the United States, the physician has no ethical or legal obligation to educate the patient on FDA regulatory status when a drug is used. However, it is the physician's responsibility to be aware of details in the drug label, including pharmacology, toxicology, and chemistry (buffers, preservatives, antioxidants, and incompatibility with other drugs).

Anesthesiologists must also consider the unfortunate litigious climate of medicine. Drug manufacturers, the FDA, and the PDR all recognize the clinically observed, safe, and effective uses of a variety of medicines although they may not be supported by well-controlled, evidence-based data. However, courts and judges have the ultimate authority over a physician's liability to practice off-label pharmacology (e.g., gabapentin and suicide risk). To be found liable for off-label drug use, the patient must prove that the anesthesiologist committed a breach of duty of care, that the breach resulted from a failure to reach the standard of care required by the law, and that the breach of duty resulted in injury. However, patient harm related to an off-label use of a medication may ultimately be the prescriber's responsibility.

While it is illegal for drug manufacturers to market off-label uses of their products, recent high-profile lawsuits against pharmaceutical manufactures indicate promotion of off-label uses is a common practice. Insys Therapeutics paid a $1.1 million fine to the State of Oregon and $2.9 million to New Hampshire for aggressive marketing of unapproved off-label uses of the opioid Subsys. Johnson and Johnson paid an

astonishing $1.391 billion fine for off-label promotion of Risperdal, Invega, and Natrecor. It should be recognized that it is also illegal for drug representatives to discuss off-label use and this information should be obtained from the medical literature although recent Federal Court of Appeals case have steadily eroded these restrictions. The ultimate decision to use a drug off-label is appropriately made by an individual physician for an individual patient.

At this point, you are probably wishing that pharmaceutical companies would perform more clinical trials so that you wouldn't need to use these drugs off-label. Filing for FDA approval for a new indication requires ~$2 million. In order to "offset" that cost as well as the significant risk involved, the Waxman-Hatch Act allows the FDA to grant market exclusivity for that drug in the new indication—as if it was only recently discovered. This allows drug companies to perform a modern safety study on drugs that have been used for decades and be rewarded with the carte blanche regarding pricing. So, that is why vasopressin is now only sold by Endo International Plc in the United States as their branded version Vasostrict and a price tag that has increased ten-fold over the previous off-label, "poorly studied" medication. Other examples include colchicine (Colcrys) and neostigmine (Bloxiverz).

Off-label drug use by anesthesiologists is a common and widely recognized practice. Off-label use should be based on the current medical literature and with the acknowledgment that there is no better, FDA-approved drug available. In addition, consideration should be given to the current legal action surrounding the drug. For anesthesiologists who primarily administer drugs in the hospital setting, it may also be wise to educate and inform the patient via literature included with the consent for care received upon admission. Table 63.1 describes eight drugs and their approved and off-label uses.

**Table 63.1 ■ Eight Drugs and Their Approved and Off-Label Uses**

| | Propofol | Fentanyl | Bupivacaine | Clonidine | Ketamine | Dexmedetomidine | Sufentanil | Neurontin |
|---|---|---|---|---|---|---|---|---|
| Description | • Propofol is a hindered phenol compound with IV general anesthetic properties. The drug is unrelated to any of the currently used barbiturate, opioid, benzodiazepine, arylcyclohexylamine, or imidazole IV anesthetic agents. | • Binds stereospecific receptors at multiple CNS sites; increases pain threshold; alters pain perception; inhibits ascending pain pathways. | • Blocks both the initiation and conduction of nerve impulses by decreasing the neuronal membrane's permeability to sodium ions, which results in inhibition of depolarization with resultant blockade of conduction. | • Stimulates $\alpha_2$ adrenoreceptors in the brainstem to activate inhibitory neuron-decreased sympathetic outflow from CNS; decreased PVR, renal vascular resistance, HR, BP.<br>• Relief of epidural pain at spinal presynaptic, postjunctional $\alpha_2$ adrenoreceptors by preventing transmission of pain signals. | • Blockade of neuronal postsynaptic NMDA receptor. Direct action on cortex and limbic system. Stimulates release of endogenous catecholamines that maintain BP and HR. Reduces polysynaptic spinal reflexes. | • Select $\alpha_2$ agonist that decreases activity in noradrenergic neurons in the brain stem. Inhibitory GABA neurons in the ventrolateral preoptic nucleus are increased. | • Binds opioid receptors in the CNS to open $K^+$ channels and inhibiting $Ca^{2+}$ channels; increases pain threshold; alters pain perception; inhibits ascending pain pathways; short-acting narcotic. | • Mechanism of action unknown; similar properties to other anticonvulsants; structurally similar to GABA. |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Approved uses | • Induction of anesthesia for inpatient or outpatient surgery in patients aged ≥3 yrs; maintenance of anesthesia for inpatient or outpatient surgery in patients aged >2 mo; in adults, for the induction and maintenance of monitored anesthesia care sedation during diagnostic procedures; treatment of agitation in intubated, mechanically ventilated ICU patients. | • Injection: sedation, relief of pain, preoperative medication, adjunct to general or regional anesthesia.<br>• Transdermal: Management of moderate-to-severe chronic pain.<br>• Transmucosal (Actiq): Management of breakthrough cancer pain.<br>• Sedation for minor procedures/analgesia: For children aged 1–12 yrs; for children aged >12 yrs, refer to adult dosing.<br>• Continuous sedation/analgesia: For children aged 1–12 yrs. Chronic pain management: For children aged ≥2 yrs (opioid-tolerant patients). Transdermal: refer to adult dosing. | • Local anesthesia: Infiltration: 0.25% infiltrated locally; maximum: 175 mg.<br>• Caudal block (preservative free): 15–30 mL of 0.25% or 0.5%.<br>• Epidural block (other than caudal block; preservative free): peripheral nerve block: 5 mL of 0.25% or 0.5%; max: 400 mg/dL.<br>• Sympathetic nerve block. Retrobulbar anesthesia.<br>• Spinal anesthesia: Preservative-free solution of 0.75% bupivacaine in 8.25% dextrose. | • Acute hypertension, hypertension.<br>• Pain management:<br>• Epidural infusion. Starting dose: 30 mcg/hr; titrate as required for relief of pain or presence of side effects; minimal experience with doses >40 mcg/hr; should be considered an adjunct to intraspinal opiate therapy.<br>• Warning against using as epidural for perioperative, obstetric, or postpartum pain because of possible bradycardia or hypotension.<br>• ADHD in children. | • Induction and maintenance of general anesthesia; sedation; analgesia. | • Sedation for intubated/sedated patients in ICU for <24 hrs. Sedation of nonintubated patients prior to or during surgical procedure. | • 10–50 mcg/kg for induction w/10–50 mcg PRN.<br>• Pediatrics: ages 2–12 yrs, 10–25 mcg/kg induction; 1–2 mcg/kg maintenance (total dose). | • Adjunct for partial seizures with and without secondary generalized seizures in patients aged >12 yrs.<br>• Adjunct therapy for partial seizures in pediatric patients aged 3–12 yrs.<br>• Management of posttherapeutic neuralgia in adults. |
| Off-label uses | • Postoperative antiemetic; refractory delirium tremens (case reports); MAC for all pediatric patients. | • Epidural or intrathecal. Children aged <2 yrs. | • Isobaric intrathecal.<br>• Pediatric patients aged <12 yrs. | • Pediatric emergence delirium.<br>• Heroin or nicotine withdrawal; severe pain; dysmenorrhea; vasomotor symptoms associated with menopause; ethanol dependence; prophylaxis of migraines; glaucoma; diabetes-associated diarrhea; impulse-control disorder; ADHD; clozapine-induced sialorrhea. | • Obstetric patients.<br>• Pediatric patients aged <16 yrs. | • Pediatric sedation for surgical procedures. Pediatric intubated/sedated patient in ICU setting. Agitation: Intranasal. | • Intrathecal. | • Chronic pain.<br>• Bipolar disorder.<br>• Social phobia.<br>• Postoperative pain. |

ADHD, attention-deficit/hyperactivity disorder; BP, blood pressure; CNS, central nervous system; HR, heart rate; ICU, intensive care unit; IV, intravenous; PVR, pulmonary vascular resistance.

## TAKE HOME POINTS

- Have you actually read the FDA labels for all of the drugs you use? If not, you should immediately do that.
- Off-label drug use is widely accepted and extremely common. Off-label drug use is even acknowledged with the FDA label itself.
- The FDA itself does not seek to prevent physicians from off-label drug use. According to the FDA, "once a product has been approved for marketing, a physician may prescribe it for uses in treatment regimens or patient populations that are not included in approved labeling. Valid new uses for drugs already on the

market are often first discovered through serendipitous observations and therapeutic interventions."

- At present, in the United States, physicians do not have a duty to advise the patient of the status of a prescribed drug as off-label or on-label.
- The legal duties and obligations pertaining to off-label drug use are somewhat complicated. Ultimately, it is the prescribing physician who sometimes holds the responsibility for patient harm from the off-label use of a drug.
- Drug makers and their sales representatives may not legally market or discuss the off-label uses of a drug although the courts do not scrupulously uphold these legal requirements.
- Drug companies can perform studies on old drugs that were never formally approved and gain market exclusivity and be permitted to raise drug prices several-fold; for example, vasopressin, neostigmine.

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# Perioperative Beta-Blocker Therapy for High-Risk Patients Having Noncardiac Surgery—New Data, New Recommendations

Esther Sung, MD and Dustin McGirr, DO

Perioperative adverse cardiovascular events (PACE) among high-risk patients who are having noncardiac surgery are relatively common. These events confer additional risk of other serious complications including death, and add significantly to health care costs. Relatively simple methods exist for risk stratification of these patients, including indices such as Goldman's original cardiac risk index and Lee's revised cardiac risk index (rCRI). However, few effective interventions exist for reducing the incidence of PACE and decreasing the associated morbidity and mortality. The risk stratification schemes mentioned above are based on the clinical history and symptoms. In addition to these, noninvasive testing, cardiac catheterization, and for some subgroups, subsequent myocardial revascularization, together with careful perioperative monitoring, are often cited as methods to reduce the risk of PACE. In terms of available pharmacologic interventions, the perioperative use of beta-adrenergic receptor blockers was often advocated as a safe and effective way of decreasing PACE after noncardiac surgery, but recent evidence has questioned the safety of initiating perioperative beta blockade.

Although the majority of evidence suggests that beta blockade is effective in reducing PACE after noncardiac surgery, especially for high-risk surgical patients, many recent studies have shown no decrease in overall mortality and some have even shown increased mortality—primarily due to strokes—with beta-blocker initiation immediately prior to surgery. For which patients is the perioperative use of beta blockade actually indicated? Are there patients who could be harmed by such treatment? Does it matter which beta blocker is used? How early should beta blockade be started?

## Perioperative Studies

Among the earliest reports of the beneficial effect of perioperative beta blockade was the randomized trial of atenolol reported by Mangano et al. In this study, a relatively brief exposure to atenolol in the perioperative period was associated with morbidity

and mortality improvement measured as late as 2 years after the surgery. Since that publication, numerous studies have been published using various beta-blocking medications in varying doses and most of these studies show improvements in PACE associated with the perioperative use of beta blockade. Moreover, Lindenauer's large-scale retrospective analysis assessed 122,338 patients who underwent noncardiac surgery and received perioperative beta blockade, and showed an apparent relationship between underlying health status and effective benefit from the treatment. Using the rCRI, patients who had no or only minor cardiovascular risk (rCRI score of 0 or 1) had no benefit and possibly a worsened outcome associated with beta blockade. However, patients with an rCRI score of 2, 3, or 4 had benefit (odds ratio for in-hospital death less than 1) associated with beta-blocker treatment. And perhaps more interesting, this risk reduction improved as the rCRI score increased: the higher the risk, the greater the apparent risk reduction from beta blockade.

## More Recent Studies

The more recent and better-powered studies surrounding perioperative beta-blocker usage consistently demonstrate that rates of PACE are reduced with the use of beta blockers; however, the overall mortality benefit is controversial. The two largest studies showing contradictory mortality benefits are the DECREASE trials and the POISE trial. The DECREASE trials reported a relative risk reduction of PACE at an astounding 60% to 95% with a relative risk of all-cause death of 0.42 (95% CI, 0.15–1.22). Unfortunately, an investigative committee from the Erasmus University found that the DECREASE trials did not properly collect data and in many cases contained fabricated data which could account for this suspicious effect size. This data has not officially been revoked from the literature, so it is frequently included during discussions about perioperative beta-blocker usage, but caution is advised when using this data to make conclusions.

On the other hand, the POISE trial showed an increase in all-cause death with a relative risk of 1.33 (95% CI, 1.03–1.73) with the use of perioperative beta blockers. Even though the study did show a reduction in PACE, the mortality benefit was offset by an increase in stroke, hypotension, and bradycardia. The major criticism of the POISE trial, however, was the usage of a high-dose, long-acting, nonspecific beta blocker (metoprolol at high doses) initiated <1 day prior to the procedure.

After excluding the controversial and dominating DECREASE and POISE trials, Wijeysundera compared data from the majority of other studies looking at perioperative beta blockade and consistently found a reduction of PACE. However, like the POISE trial, there was still an increased risk of stroke, hypotension, and bradycardia yielding an all-cause death relative risk of 1.17 (95% CI, 0.70–1.94). Unfortunately, these

studies are not well powered and do not evaluate the usage of more selective beta-1 blockers or the initiation of therapy >1 day prior to the procedure. There appears to be a consistent trend of improved cardiac outcomes at the expense of stroke, hypotension, and bradycardia yielding no significant mortality benefit when initiating a beta blocker <1 day prior to a noncardiac surgery. There is a need for well-powered studies that evaluate the mortality benefit of using more selective beta-1 blockers that are started earlier in the perioperative course and titrated to minimize perioperative stroke, hypotension, and bradycardia. A chart review of various agents found fewer strokes with atenolol than metoprolol. This was attributed to atenolol's higher $\beta_1$:$\beta_2$ specificity and longer half-life than metoprolol.

## Task Force Guidelines

The American College of Cardiology/American Heart Association (ACC/AHA) Task Force on Practice Guidelines has recently released a 2014 updated guideline specific to perioperative beta-blocker usage which is summarized below:

**Class I recommendation (is recommended):**

) "Beta blockers should be continued in patients undergoing surgery who have been on beta blockers chronically (level of evidence B)." Teichert et al. presented evidence that abrupt cessation of beta blockers in the perioperative period has been associated with a higher risk of MI in the first 30 days with a relative risk of 2.7 (95% CI; 1.07–5.59). Multiple other studies have shown a similar trend. We advise that perioperative beta-blocker withdrawal be avoided unless medically necessary to do so with potential titration of beta-blocker dose to maintain heart rate goals without hypotension.

**Class IIa recommendation (is reasonable to consider):**

) "It is reasonable for the management of beta blockers after surgery to be guided by clinical circumstances, independent of when the agent was started (level of evidence B)." Clinical judgment should be used to adjust the dose or temporarily withhold beta blockade in the setting of significant hypotension, bradycardia, or bleeding.

**Class IIb recommendation (may be reasonable to consider):**

) "In patients with intermediate- or high-risk myocardial ischemia noted in preoperative risk stratification tests, it may be reasonable to begin perioperative beta blockers (level of evidence C)." The decision to initiate a beta blocker due to high cardiovascular risk should be weighed against the risks of stroke or other contraindications.

) "In patients with 3 or more rCRI risk factors, it may be reasonable to begin beta

blockers before surgery (level of evidence B)." Patients with three or more rCRI risk factors also seem to benefit from perioperative beta-blocker therapy. As mentioned previously, the risk of stroke or other contraindications with beta-blocker therapy should be considered.

) "In patients with a compelling long-term indication for beta-blocker therapy but no other rCRI risk factors, initiating beta blockers in the perioperative setting as an approach to reduce perioperative risk is of uncertain benefit (level of evidence B)." It could be preferable to initiate beta-blocker therapy as soon as possible after a procedure if there is a long-term indication without additional rCRI risk factors.

) "In patients in whom beta-blocker therapy is initiated, it may be reasonable to begin perioperative beta blockers long enough in advance to assess safety and tolerability, preferably more than 1 day before surgery (level of evidence B)." Starting a beta blocker 2 to 7 days prior to surgery may be preferable.

**Class III recommendation (is not recommended):**

) "Beta-blocker therapy should not be started on the day of surgery (level of evidence B)." Starting beta blockers <1 day before surgery, especially high-dose, long-acting forms in naive patients, has the highest risk of causing harm to the patient.

There are instances where patients present for surgery but have failed to initiate the intended perioperative beta-blocker therapy. Or perhaps, despite being compliant with the prescribed beta blocker, the patient's heart rate is still significantly higher than the cardiology consult recommends. What should the anesthesiologist do? There is not just one answer since every clinical scenario is unique, but a good approach would involve a discussion with both the surgeon and the patient regarding the urgency of the surgery and potential for postponement to allow for beta-blocker therapy optimization. If the decision is to proceed with surgery, one must consider the increased cardiovascular risk of proceeding without beta-blocker optimization and the increased risk of stroke, hypotension, and bradycardia if beta-blocker therapy is initiated or increased. An alternative approach may be the use of a short-acting beta blocker, like esmolol, to blunt the adrenergic response of laryngoscopy, surgical stimulus, and emergence. Its short elimination half-life might reduce the incidence of hypotension that may be encountered with longer-acting agents once the stimulus has passed. In 2011, Savio published a systematic review looking at the safety and efficacy of perioperative esmolol and concluded that titration of esmolol to a hemodynamic end point (avoiding hypotension) can be safe and effective in providing protection against myocardial ischemia in patients undergoing noncardiac surgery.

## TAKE HOME POINTS

- Perioperative cardiovascular events after noncardiac surgery are common and a source of significant morbidity and mortality.
- The majority of evidence suggests that beta blockade is effective in reducing PACE after noncardiac surgery, especially for high-risk surgical patients; however, these benefits should be weighed against the increased risks of stroke, hypotension, and bradycardia.
- The only class I recommendation by the ACC/AHA guidelines is to continue perioperative beta blockers if the patient has been on them chronically.
- The only class III recommendation is NOT to start beta blockers on the day of surgery as this could potentially be harmful.
- More research is needed to evaluate perioperative beta-blocker therapy specifically looking at more selective beta-1 blockers started earlier in the perioperative course.
- An alternative approach to initiating long-acting beta-blocker therapy on the day of surgery is to use a short-acting beta blocker, like esmolol, for protection against myocardial ischemia during the stimulating events of surgery.

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# Should I Withhold or Continue Angiotensin Receptor Blockers in the Perioperative Period?

Thomas B. Comfere, MD and Juraj Sprung, MD PhD

In general, the decision to withhold or continue medications with cardiovascular effects in the perioperative period depends on the risk balance between the deleterious interaction of the drug with anesthetics and possible morbidity resulting from hemodynamic and neurohumoral effects that may occur due to withdrawal of these medications.

## Indications

Drugs that affect the renin–angiotensin system, such as angiotensin-converting enzyme inhibitors (ACEIs) and angiotensin II receptor subtype 1 antagonists (ARA), also known as angiotensin receptor blockers (ARBs), are often used in the management of hypertension, congestive heart failure, and diabetic nephropathy. ACEI/ARA can interfere with the regulation of arterial blood pressure by several mechanisms, including sympathetic blockade, decrease in responsiveness to $\alpha_1$-adrenergic agonists, impaired degradation of bradykinin (which promotes vasodilation), and inhibition of the receptor binding of angiotensin II. Some of the main benefits of ACEI/ARA are blood pressure control, myocardial anti-ischemic effects, and end-organ protection that is thought to be independent of their blood-pressure–lowering properties.

## Perioperative Guideline

The 2014 ACC/AHA Perioperative Guideline recommends the perioperative continuation of chronically administered β-blockers, $\alpha_2$ adrenergic agonists (e.g., clonidine), and calcium-channel blockers. ACEI/ARA therapy, while heavily utilized, has not been well studied in the perioperative period and evidence regarding perioperative management of these medications is limited mostly to observational studies. The 2014 ACC/AHA Perioperative Guideline states “continuation ACEI/ARA

in the perioperative period is reasonable." These recommendations are based on the lack of evidence at the time of writing of the guidelines that continuation of ACEI/ARA in the perioperative period may lead to increased cardiovascular morbidity and mortality. In contrast to published guidelines that focus on major cardiovascular endpoints in nonanesthetized patients, clinical management of these patients has to take into account that refractory intraoperative hypotension, frequently seen if these medications are not preoperatively interrupted, may be harmful. Over the last several years, evidence is slowly accumulating that withholding of ACEI/ARA in the perioperative period may be reasonable, as continuation of ACEI/ARA can lead to hypotension difficult to treat which may lead to adverse cardiovascular outcomes. Preoperative withdrawal of ACEI/ARA therapy has been initially proposed on the basis of several case reports of intraoperative hypotension refractory to common treatments such as fluid boluses or intravenous ephedrine and phenylephrine. Several observational studies showed an increased frequency of hypotension after the induction of anesthesia when ACEI/ARA therapy was continued through the morning of surgery compared with discontinuation of therapy the night before surgery (Fig. 65.1). The recent publication of an analysis of vascular events in a large prospective cohort study (VISION) provides evidence that withholding ACEI/ARB in the 24 hours prior to noncardiac surgery reduces the rate of a composite outcome of postoperative all-cause death, stroke, or myocardial injury. This analysis is based on a very large patient cohort and while it does not provide evidence from a randomized trial, it gives further strong evidence of the benefit of withholding ACEI/ARB in the perioperative period.

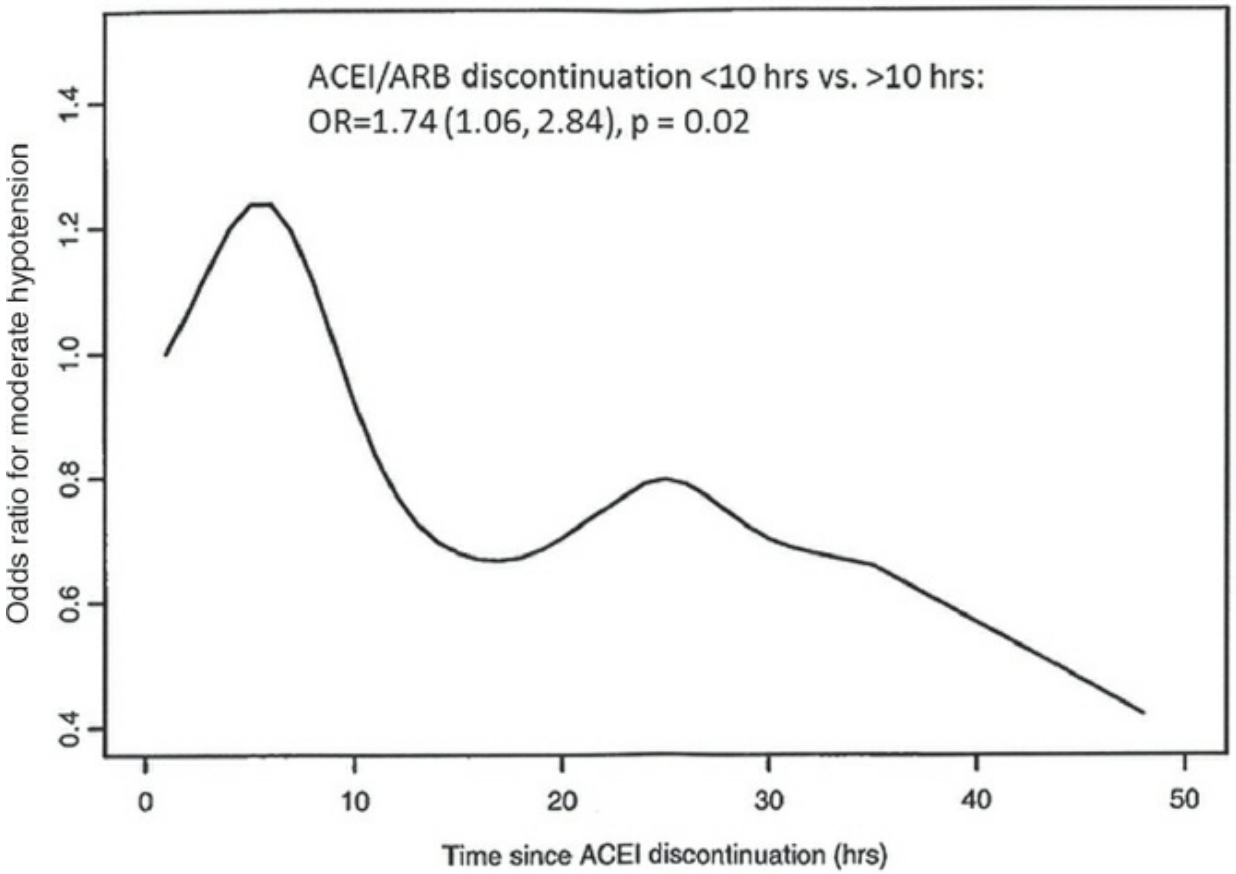


**Figure 65.1.** The likelihood of developing moderate hypotension versus time since last ACEI/ARA dosing. After anesthetic induction Comfere et al. showed that 54% of the entire population developed moderate hypotension. While hypotension occurred even in patients who stopped their ACEI/ARA therapy the day before surgery, omitting the therapy at more than 10 hours before anesthesia substantially reduced the likelihood of developing hypotension. (Reprinted with permission from Comfere T, Sprung J, Kumar MM, et al. Angiotensin system inhibitors in a general surgical population. Anesth Analg. 2005;100(3):636–644. Copyright © 2005 International Anesthesia Research Society.)

## Should Therapy Be Continued Uninterrupted in the Perioperative Period?

There are proponents who believe that ACE/ARB therapy should be uninterrupted in the perioperative period. This notion is based on early laboratory and observational clinical study that suggests possible benefits of perioperative use of ACEI/ARA specifically related to decrease in ischemia-related myocardial cell damage in cardiac surgery and improved renal plasma flow and creatinine clearance in patients undergoing cardiopulmonary bypass. The mechanism of renal protection is thought to be through an ACEI/ARA-mediated attenuation of cardiopulmonary-bypass–associated renal vascular constriction, leading to an increase in the renal blood flow and glomerular filtration rate. Findings that ACEI/ARA may provide renal protection are not consistent across studies and published meta-analyses don't show a benefit when pooled results are analysed. In contrast, evidence is now accumulating that ACEI/ARBs may interfere with

renal autoregulation. Patients with chronic kidney disease (eGFR <60 mL/min/1.73 $m^2$) and patients with normal renal function who are treated with an ACEI/ARB are at risk of development of acute kidney injury if they develop hypovolemia and hypotension, which are likely encountered in patients with uninterrupted preoperative ACEI/ARA therapy.

## Timing of Last Dose

An observational study by Comfere et al., showed that the timing of the last ACEI/ARA dose was a major determinant of the frequency of postinduction hypotension. During the first 30 minutes after anesthetic induction, moderate hypotension was more frequent in patients whose most recent ACEI/ARA dose was taken within 10 hours compared with those whose last dose was taken more than 10 hours before induction (Fig. 65.1). These findings can be explained by the elimination half-lives of ACEI/ARA drugs (Table 65.1). Specifically, a 10-hour interval between the last dose and anesthetic induction corresponds to the average half-life of an ACEI/ARA and appears to be sufficient to decrease the incidence of hypotensive episodes after anesthetic induction. In humans, most ACEIs are eliminated renally via glomerular filtration or tubular secretion. Renal insufficiency may have a substantial effect on the half-life of certain ACEIs, and the altered pharmacokinetics of ACEIs in chronic renal failure may be a potential hazard; thus, abstinence for longer than 10 hours before surgery may be considered in patients with renal insufficiency.

**Table 65.1 ■ Elimination Half-Lives of Angiotensin-Converting Enzyme Inhibitors and Angiotensin-Receptor Antagonists**

| Drug | Active Metabolite | Half-Life (hrs) |
|---|---|---|
| Angiotensin-converting Enzyme Inhibitors | | |
| Benazeprilat | Benzaprilat | ≈ 11 |
| Captopril | | ≈ 2 |
| Enalapril | Enalaprilat | ≈ 11 |
| Fosinopril | Fosinoprilat | ≈ 12 |
| Lisinopril | | ≈ 12 |
| Perindopril | Perindoprilat | |
| Quinapril | Quinaprilat | ≈ 2 |
| Ramipril | Ramiprilat | Range, 9–18 |

| | | |
|---|---|---|
| Zofenopril | Zofenoprilat | ≈ 36 |
| Angiotensin-receptor Antagonists | | |
| Azilsartan medoxomil | Azilsartan | ≈ 11 |
| Candesartan | | Range, 5.1–10.5 |
| Eprosartan | | ≈ 20 |
| Irbesartan | | 11–15 |
| Losartan | E-3174 | Range, 6–9 |
| Olmesartan medoxomil | Olmesartan | ≈13 |
| Telmisartan | | ≈24 |
| Valsartan | | Range, 6–9 |

Modified with permission from Comfere T, Sprung J, Kumar MM, et al. Angiotensin system inhibitors in a general surgical population. Anesth Analg. 2005;100(3):636–644. Copyright © 2005 International Anesthesia Research Society.

Vasopressin or vasopressin analogs (e.g., terlipressin) have been advocated in patients on ACEI/ARA therapy to treat hypotension that is refractory to other measures (usually 1 to 2 units of vasopressin IV push). Other frequently used treatments for hypotension after induction of general anesthesia in the context ACEI/ARA are potent vasopressor infusions such as norepinephrine and epinephrine.

Some clinicians continue ACEI/ARA in the perioperative setting because of a concern for uncontrollable postoperative rebound hypertension. Multiple previous studies have shown that stopping ACEIs and ARAs in patients on the day of surgery does not result in a clinically significant increase of the incidence of pre- or postoperative hypertension. It is the experience of authors of this chapter that postoperative hypertension in patients who did not receive their usual preoperative dose of ACEI/ARA is effectively treated with IV labetalol, hydralazine, or enalaprilat.

## TAKE HOME POINTS

- Intraoperative hypotension refractory to the usual therapeutic interventions in the setting of uninterrupted ACEI/ARA use has been frequently described.
- In patients receiving chronic ACEI/ARA therapy who receive general anesthesia, the administration of these drugs within 10 hours before anesthesia is an independent risk factor for the development of moderate hypotension after anesthetic induction.
- A recent analysis of a large, prospectively collected cohort of patients undergoing noncardiac surgery provides evidence that withholding ACEI/ARB in the 24 hours

prior to noncardiac surgery reduces the rate of a composite outcome of postoperative all-cause death, stroke, or myocardial injury.

- Preoperative withholding of ACEI/ARA therapy should be considered for all patients who may be especially prone to hypotension-associated complications (e.g., patients with severe aortic stenosis or cardiovascular disease).

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# Stop Metformin Before Elective Surgery or Intravascular Contrast Dye Study to Decrease the Risk of Lactic Acidosis

Immaculeta Achilike, MD MPH and Serge Jabbour, MD FACP FACE

Metformin is an insulin-sensitizing agent that has been in use for more than 50 years. It is the most prescribed oral hypoglycemic agent in the world. Chemically, metformin is a biguanide. Its main action is to increase peripheral glucose utilization and decrease hepatic glucose release. In overweight patients with type 2 diabetes, metformin has been shown to lower cardiovascular and diabetes-related deaths and has been considered the oral hypoglycemic agent of choice. It is also indicated to treat the insulin resistance of polycystic ovary syndrome. Metformin is excreted renally and has a half-life of 4 to 9 hours. Metformin is available as the branded drugs Glucophage, Glucophage XR tablets, Glumetza, Fortamet tablets, and Riomet liquid. It is also a component of several combination drugs: Komboglyze, Actoplus Met, Glucovance, Metaglip, PrandiMet, and Avandamet.

## Lactic Acidosis

Lactic acidosis is a type B (nonhypoxic), high-anion-gap acidosis. Lactate is produced by anaerobic glycolysis, and the development of lactic acidosis requires overproduction, slowed breakdown, or both. At high blood levels, metformin produces severe refractory lactic acidosis by the uncoupling of oxidative glycolysis, thus driving cellular mechanisms toward anaerobic metabolism.

Lactic acidosis associated with metformin is rare but has a mortality of 50%. The risk with chronic use in the outpatient setting ranges from 1/1,000 to 1/30,000 patient-years. Patients in the acute care setting, however, incur an additional risk because they are exposed to situations, such as transient or ongoing renal insufficiency, that may lead to drug accumulation and increases in drug levels. As such, surgery or exposure to iodinated radiologic contrast dye (seen with angiography and intravenous contrast for computed tomography scan) must prompt discontinuation of metformin. Other clinical situations that may precipitate lactic acidosis in patients taking metformin include

advanced age, dehydration, liver disease, congestive heart failure, chronic alcohol abuse or binge drinking of alcohol, shock with tissue hypoperfusion (septic, cardiogenic, etc.), and hypoxia.

## Guidelines

A Cochrane review of 347 studies did not demonstrate an increased risk of lactic acidosis in patients treated with metformin on the day of surgery who had normal renal function. Despite these findings, for both surgical patients and patients receiving contrast, **guidelines continue to recommend holding metformin on the day of surgery**. Generally, endocrinology consultants recommend that metformin be withheld on the day of surgery or contrast dye study only or at most for 24 hours. The Joint British Diabetes Society includes guidelines that advise continuing metformin on the day of surgery for patients who had a short starvation period (missed one meal). For radiology patients, there is some controversy on timing of metformin. Metformin should be held for at least 48 hours for patients with a GFR <60 mL/min and restarted 48 hours after contrast administration and only after renal function is stable (<25% increase in baseline creatinine). For patients with known normal renal function and/or who receive small volumes of contrast (<100 mL of intravenous contrast), it may be unnecessary to hold metformin or do any additional testing. In addition, surgical patients should have resumption of adequate oral caloric intake prior to resumption of metformin.

### TAKE HOME POINTS

- Metformin is the most commonly prescribed oral hypoglycemic agent in the world. It is a biguanide compound that acts to increase peripheral utilization and decrease hepatic glucose release. It has a medium-length half-life and is renally excreted.
- Metformin is prescribed for overweight patients who have type 2 diabetes and for certain patients with insulin resistance.
- Perioperative acute kidney injury can increase plasma metformin levels and high blood levels of metformin can produce severe refractory lactic acidosis by uncoupling oxidative glycolysis.
- Metformin-induced lactic acidosis is rare, but can be deadly—it is associated with mortality rates up to 50%.
- Multiple studies have not demonstrated an increase in morbidity or mortality with day-of-surgery administration of metformin in patients with normal renal function. Remember, however, that patients can experience decrements in renal function in the perioperative period.
- Guidelines generally recommend that metformin be held on the day of surgery.

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# Should I Administer Steroids in the Perioperative Period?

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Corticosteroid medications are commonly administered during the perioperative period. Indications include postoperative nausea and vomiting (PONV) prophylaxis, treatment of airway edema, induction of immunosuppression, and "stress dosing" for adrenal suppression. Despite widespread use, corticosteroids have well-known side effects including hyperglycemia, immunosuppression, hypertension, possibly wound infection, and delayed wound healing. Anesthesia providers should understand these effects when making decisions regarding the administration of these medications.

## Hyperglycemia

Most corticosteroid medications have glucocorticoid properties which stimulate gluconeogenesis and impair the effects of insulin on glucose uptake, resulting in hyperglycemia. Chronic use of corticosteroids results in impaired glucose tolerance or even diabetes. Perioperative administration of a corticosteroid medication is typically limited to a single dose, for example, for PONV prophylaxis. A large meta-analysis found that a single dose is sufficient to increase serum glucose levels for 6 to 12 hours. However, this increase is usually modest and of little clinical significance, with a weighted means increase of 20 mg/dL in all patients and 14.0 mg/dL when excluding diabetics.

Dexamethasone is the most commonly administered corticosteroid and is often used for PONV prophylaxis. Doses range from 4 to 10 mg. While dexamethasone reduces the incidence of PONV alone, it works synergistically with other antiemetic medications including 5-HT3 receptor antagonists (e.g., ondansetron, granisetron) and butyrophenones (e.g., droperidol, haloperidol). When used in combination with other antiemetics, the 4-mg dose is adequate and may limit hyperglycemia. However, caution should be used when considering administration of dexamethasone for PONV prophylaxis in diabetics who are brittle or poorly controlled.

## Wound Healing and Infection

Corticosteroids have immunosuppressive properties, and patients on chronic steroids may be at increased risk for opportunistic infections, such as pneumocystis pneumonia. In the case of organ transplantation, this is used to the clinician's advantage and reduction of the rate of allograft rejection is an indication for corticosteroid administration. On the other hand, this same property raises concerns that the perioperative administration of corticosteroids could increase the risk for surgical infection. Chronic steroid therapy is associated with two to five times higher rate of wound complications in surgical patients. Fortunately, meta-analyses have not found evidence that perioperative corticosteroid administration increases wound infection with both cardiac and noncardiac surgery. A large prospective trial of patients undergoing open heart surgery randomized to receiving dexamethasone or placebo found similar rates of wound infection and even lower rates of pneumonia in the steroid group. However, repeated or cumulative exposure to steroids may increase risk. For example, longer duration of steroid administration to children undergoing complex cardiac surgery was correlated with increased rates of wound infection.

## Steroid Withdrawal

One of the physiologic responses to stress is increased secretion of the glucocorticoid cortisol by the adrenal glands. Under normal conditions, cortisol levels are tightly regulated via the hypothalamic–pituitary–adrenal (HPA) axis. A variety of diseases are known to interfere with cortisol regulation. Decreased activity of any of these three endocrine glands (e.g., autoimmune adrenalitis or Addison's disease) can result in adrenal insufficiency—insufficient production of cortisol. Exogenous glucocorticoids suppress cortisol production via inhibition of HPA axis vis-à-vis decreased production of corticotropin-releasing hormone and pituitary adrenocorticotropic hormone. Prolonged exposure to exogenous glucocorticoids can result in adrenal gland atrophy and persistent adrenal dysfunction (it is believed, effects may last up to 6 to 12 months following discontinuation of glucocorticoid medication). Under these conditions, patients may not be able to generate sufficient levels of cortisol during periods of stress resulting in an adrenal crisis, which can be life threatening. Under anesthesia this could manifest as recalcitrant hypotension, hypoglycemia, fever, and electrolyte abnormalities (hyponatremia, hyperkalemia, and hypercalcemia). An unanesthetized patient could also present with lethargy, confusion, or seizures.

To avoid an adrenal crisis, such patients may require supplemental glucocorticoid administration during surgery or other physiologic periods of stress. Traditionally, based on early research of the adrenal response to stress, 300 mg of cortisol equivalents were administered in divided doses on the day of surgery as "stress-dose" steroids. A

common regimen was three intravenous doses of 100 mg hydrocortisone (at the beginning, during and end of surgery, or every 8 hours). Current evidence suggests that the adrenal response to stress ranges from 50 mg (stress response to minor surgery) to 100 mg (stress response to major surgery). Based on this new information, lower doses of "stress dose" are being advocated.

Increased understanding of HPA axis suppression has also narrowed the indication for which patients require supplemental glucocorticoids. Patients taking 5 mg of oral prednisone daily (or equivalent) are not considered HPA-axis suppressed (unless this replacement is prescribed for primary adrenal insufficiency), and continuation of their daily dose should be sufficient. Patients taking greater than 20 mg of prednisone daily should be considered HPA-axis suppressed, and likely require corticosteroid supplementation for intermediate or major surgery. Management of patients taking intermediate doses undergoing major surgery or taking high doses undergoing low-risk surgery depends on clinical circumstances. Such patients should continue their daily dose, but decisions regarding supplementation should be at the anesthesiologist's discretion. However, supplementation should be considered for refractory hypotension for any patient who has used steroid medications within the past 12 months.

## Other Complications

Hypertension is a known side effect of chronic corticosteroid therapy, but may also occur after a single dose. This is thought to be due to a combination of many factors, including increased plasma volume, vascular tone, and cardiac output. Acute mental status changes are rare after single-dose administration, but include insomnia, excitability, and confusion. Corticosteroid administration in pediatric patients with glioblastoma may decrease survival, likely due to increased blood glucose levels. Corticosteroids in patients presenting for biopsy of suspected malignancy may affect the accuracy of pathologic diagnosis, which could ultimately impact diagnosis, staging, and/or treatment. Ideally, administration of corticosteroids in these patients should be delayed until after the biopsy is obtained.

### TAKE HOME POINTS

- Dexamethasone is commonly used for PONV prophylaxis and the 4-mg dose is likely sufficient when combined with other antiemetics.
- Transient, but usually clinically irrelevant, hyperglycemia occurs following steroid administration. However, caution should be used when administering these medications in brittle diabetics or hyperglycemic patients.
- Evidence suggests single-dose administration of steroids does not increase the risk

for wound infections.

- The dose of steroid replacement called for by traditional "stress-dose" steroid regimens (300 mg cortisol equivalent) is currently believed to be excessive and lower doses probably suffice.
- Patients requiring perioperative stress dosing are likely limited to those taking high daily doses (>20 mg prednisone equivalent) undergoing major or lengthy operations. However, adrenal insufficiency should be considered for any patient exposed to steroids within 12 months who has refractory hypotension.
- Corticosteroid should likely be avoided in select groups of oncology patients including glioblastoma and in patients presenting for diagnostic biopsy.

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# Beware of the Bowel Prep

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Mechanical bowel preparation (MBP) is commonly used for colonoscopy and elective colorectal surgery. Its goal is to rid the colon of solid fecal material for a clean view during colonoscopy. Preoperative use of MBP in combination with oral antibiotics has been associated with reduction in surgical site infections, anastomotic leak, and ileus following colorectal surgery. Other surgeries in which the MBP may be considered include some abdominal and pelvic operations. Contraindications to the mechanical bowel prep include complete bowel obstruction and free perforation.

Historically, agents such as castor oil, senna, bisacodyl, magnesium citrate, and sodium phosphate have all been used in conjunction with a low-residue diet. Whole-gut lavage with large volumes of isotonic solutions via a nasogastric tube has also been used. However, this technique has been associated with side effects including electrolyte abnormalities, abdominal distention, nausea, and vomiting. Mannitol, sorbitol, and lactulose have also been used, but this practice has been shown to be associated with catastrophic intraoperative explosions when gases produced from bacterial fermentation of these agents were ignited by electrocautery.

Currently in addition to a low-residue diet, the most recommended regimens for MBP are full-volume polyethylene glycol (PEG) (e.g., GoLYTELY, etc.) and low-volume PEG regimens. PEG is a nonabsorbable polymer coadministered with electrolytes for MBP. Electrolyte solutions containing PEG are iso-osmotic, usually without significant fluid and electrolyte shifts due to PEG's ability to keep the solution's electrolytes in the colon. Full-volume PEG patients are required to drink the entire 4 L of solution if split-dosing regimen is not given. To improve tolerability and compliance of the prep, split dosing is often used. Half of the full-volume PEG is taken the evening before and the other half usually 5 hours before the procedure. Low-volume regimens, usually 2 L, may include the addition of bisacodyl (HalfLytely, etc.) or ascorbic acid (MoviPrep) along with PEG. Depending on the product some of the lower-volume regimens can be administered as a split-dose preparation with evening and morning dosing. Overall, abdominal fullness, nausea, and vomiting are the most common adverse events seen with PEG agents. Although rare, arrhythmias have occurred with PEG

electrolyte solutions and the potential should be considered in high-risk cardiovascular patients (e.g., cardiomyopathy, QT prolongation, etc.).

Hyperosmotic agents such as magnesium citrate and sodium phosphate are also sometimes used and better tolerated by patients due to the relatively small volume administered. These draw water into the bowel and abdominal cramping, nausea, and vomiting are common adverse effects. Hyperosmolar agents induce a watery diarrhea following administration. A negative fluid balance can ensue, which can lead to hypovolemia that may become especially evident at the induction of anesthesia if adequate fluid replacement has not taken place. In contrast, PEG leaves the fluid balance virtually unaffected. Water and electrolytes should neither be absorbed nor excreted from the bowel. Therefore, patients do not usually exhibit hemodynamic instability during the induction of anesthesia. For these reasons, hyperosmolar agents may be more problematic especially in patients who may be vulnerable to shifts in intravascular volume. In addition, electrolyte abnormalities with hyperosmolar agents can occur and should be considered. Both problems may be exacerbated by other drugs (e.g., diuretics) that can also alter electrolytes and volume. These agents should be avoided as a preparation in patients with comorbidities more sensitive to these electrolyte and volume changes (e.g., renal insufficiency and heart failure). Other hyperosmotic preparations that contain salts such as sodium sulfate and sodium picosulfate are also recommended to be avoided in these patients.

In addition to mechanical bowel prep, bowel preparation for elective colorectal surgery typically consists of oral antibiotics and intravenous antibiotics. Infectious complications are the leading cause of morbidity and mortality in colorectal surgery. The most common infectious complications include wound infection, intra-abdominal or pelvic abscess, and anastomotic leaks. Offending micro-organisms are typically endogenous colonic flora and include Bacterioides fragilis and Escherichia coli as well a s Clostridia, Klebsiella, Proteus, and Pseudoman species. The logical goals of perioperative antibiotics include decreasing fecal load and bacterial count in the colonic lumen and achieving therapeutic tissue levels of antibiotics in the event that contamination occurs.

Combinations of neomycin plus erythromycin or metronidazole are the most commonly used agents. The benefit of these oral drugs without MBP prior to surgery has not been clearly demonstrated. Therefore, oral antibiotics used are typically given the day before surgery along with MBP. Although some oral antibiotics are not well absorbed from the gut, there is significant systemic absorption of erythromycin following oral administration.

One underappreciated problem that may arise with this protocol is the occurrence of unanticipated drug–drug interactions. Through two distinct mechanisms, erythromycin

may raise the blood levels of a large number of other drugs. First, erythromycin is a potent inhibitor of both intestinal and hepatic forms of the most important of the cytochrome P450 enzymes, CYP3A4. As such, it inhibits the metabolism of the broad array of CYP3A4 substrates, leading to increases in the blood levels of such drugs. Consideration should be given to the therapeutic index or potential toxicity of the inhibited drug. Second, erythromycin also inhibits the functioning of the extruding P-glycoprotein transporter. Thus, inhibition of this transporter also leads to increased levels of P-glycoprotein substrates such as cyclosporine, digoxin, and morphine. In addition, both erythromycin and metronidazole have been associated with QT prolongation and may increase the risk in the presence of other QT-prolonging drugs or patients with pre-existing prolonged QT pathology.

For IV prophylaxis, surgeons usually administer a second-generation cephalosporin (cefotetan, cefoxitin) or cefazolin plus metronidazole that have activity against both aerobic and anaerobic colonic bacteria. This is administered within 1 hour of skin incision and IV prophylaxis is often discontinued after wound closure. Depending on the length of procedure, renal function, and the agent administered, redosing the antibiotic regimen during surgery may be required. Continuing prophylaxis beyond the first 24 hours postoperatively has not been shown to be of any additional benefit and increases the risk of side effects, bacterial resistance, and Clostridium difficile colitis.

## TAKE HOME POINTS

- Remember that bowel preps are not used just for colorectal surgeries; ask all patients having surgery on internal viscera if they have done a prep.
- Electrolyte and volume changes may occur with both PEG and hyperosmotic preps.
- Although antibiotics are used for a short time, consider the potential of drug–drug interactions.
- Depending on length of procedure, renal function, and the antibiotic administered, anticipate the possibility of redosing the drug during surgery.

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# What Drugs Require Slow Administration?

Maggie A. Jeffries, MD, Laurel E. Moore, MD, and Catherine Marcucci, MD

The speed at which intravenous (IV) medications can be administered is often overlooked and can have devastating consequences. The drug package inserts contain information on administration, but these are frequently unavailable to anesthesiologists and the information included is not always appropriate for anesthetized patients. We often rely on pharmacists to relay important information regarding the IV administration of particular medications. As anesthesia providers, however, we frequently prepare medications for administration without pharmacy intervention. The purpose of this chapter is to review common medications that need to be administered slowly or that have other special considerations. The chapter is not intended to be used for dosing of medications. This is by no means an all-inclusive list; our intention is to cover commonly used medications that are at high risk for being administered inappropriately.

The following medications must be given slowly when they are administered intravenously: **Phenytoin, protamine, vancomycin, potassium chloride, clindamycin, thymoglobulin, furosemide, gentamicin**, **oxytocin, and lysine analogs such as aminocaproic acid and tranexamic acid.** Dexamethasone, when given in a rapid IV push, is not associated with hemodynamic instability but a significant percentage of patients will experience significantly distressful perineal burning pain and itching.

## Phenytoin (Dilantin)

Phenytoin is a neurologic and cardiac depressant and is one of the most dangerous medications we administer intraoperatively. For status epilepticus, the maximum rate of IV administration is 50 mg/min (for children, 1 to 3 mg/kg/min up to a max of 50 mg/min). Because we generally give the medication prophylactically in the operating room, it is recommended to administer phenytoin much more slowly in anesthetized patients (e.g., max. 10 to 20 mg/min). Elderly patients and patients with cardiovascular disease should also receive the medication more slowly. If phenytoin is given rapidly IV, asystole and cardiovascular collapse is possible, but more commonly hypotension, bradycardia, and cardiac dysrhythmias are seen. These effects may be related to the

diluent (propylene glycol) and may be minimized by using fosphenytoin. The dose must also be adjusted in those with hypoalbuminemia and liver disease. It is advised that the medication be diluted in normal saline to a final concentration of 1 to 10 mg/mL and be administered with an infusion pump. Extravasation of this medication can cause severe soft tissue injury, and it is therefore recommended to inject phenytoin into a large vein through a large-gauge IV catheter. Be sure to flush the line before and after administration with normal saline. This medication may be piggybacked, but there is a high potential for precipitation in the presence of other medications, so a 0.22-µm filter should be used.

## Protamine

Protamine is administered frequently in cardiac and vascular anesthesia to reverse the anticoagulant effects of heparin. Administer protamine slowly, no faster than 50 mg over 10 minutes. Severe hypotension, bradycardia, pulmonary hypertension, and an anaphylactic reaction can result if protamine is given by IV push. Patients at increased risk of severe reactions include diabetics taking insulin, patients with fish sensitivities, men who have undergone vasectomy, and patients who have been previously exposed to protamine. Dilution of the medication is not necessary.

## Vancomycin

Administration of vancomycin should be no faster than 10 mg/min and should be administered with the use of an infusion pump. “Red man” syndrome (erythematous rash on face and body) may occur, and if so, the infusion rate should be reduced. Rapid IV infusion has been reported to cause hypotension and, rarely, cardiac arrest. Vancomycin may cause soft tissue injury if it extravasates. When possible, a large-gauge IV catheter or central line should be used for administration.

## Potassium

Potassium may precipitate cardiac arrhythmias if serum concentrations increase too rapidly. In general, the maximum speed of administration is 40 mEq/hr. The patient should have electrocardiogram (EKG) monitoring in place before administration. This medication causes venous irritation, so infusion via large IV catheters is preferred. If it is not prepackaged, potassium must be diluted.

## Clindamycin

Clindamycin should be diluted before administration to a concentration of no more than 18 mg/mL. Do not “push” clindamycin intravenously, because it can cause profound

hypotension. Infuse over 10 to 60 minutes at a rate no greater than 30 mg/min. This medication can cause thrombophlebitis at the injection site.

## Thymoglobulin

Thymoglobulin (lymphocyte immune globulin or antithymocyte globulin rabbit) is often used in renal transplant patients at increased risk for rejection. Administration is through a 0.22-µm filter and is infused over at least 6 hours for the first infusion to decrease the development of fever and/or chills. Hypertension is a known side effect, but hypotension may be noted intraoperatively. Administration through a central line or other high-flow vein is preferred to decrease the risk of thrombosis or thrombophlebitis. Patients may be premedicated with corticosteroids, Tylenol, and/or antihistamines to reduce side effects.

## Furosemide (Lasix)

Lasix should also be administered slowly over 1 to 2 minutes. Administer no faster than 4 mg/min if large doses are to be given. There have been reports of acute hypotension and sudden cardiac arrest after IV administration. Ototoxicity has been associated with rapid IV infusion. Renal impairment, concurrent administration of other ototoxic medications, and excessive doses increase the risk of ototoxicity.

## Gentamicin

Gentamicin has a small therapeutic window, which can make dosing challenging. Dosing adjustments in situations of renal impairment are particularly important. Aminoglycosides in general are associated with both nephrotoxicity and ototoxicity. It is thought that toxicity is related to the dose given and the duration of therapy. There have been reports of hypotension after administration of an aminoglycoside, and it is therefore recommended that gentamicin be diluted and administered slowly. Gentamicin can potentiate neuromuscular blockade.

## Oxytocin (Pitocin)

There are multiple uses of Pitocin for obstetric patients. Infusions of Pitocin for induction of labor are managed by the obstetric staff, but anesthesia staff are often asked to administer this medication during caesarian sections and in hemorrhagic emergencies. Dilute Pitocin in either a 0.9% normal saline or lactated Ringer solution and administer slowly. Rapid administration may cause arrhythmias and/or hypertension in the mother. Uterine hyperactivity as severe as uterine hypertonicity, tetanic contraction, and uterine rupture is also possible. Be aware that Pitocin has an antidiuretic effect that may result

in water intoxication, with convulsions, coma, or death.

## Dexamethasone

Dexamethasone has a number of indications in the perioperative period, including treatment for postoperative nausea and vomiting. Dexamethasone has been noted to precipitate intense perineal pain and pruritis, especially in women, when given in a bolus via IV push. The mechanism is largely unelucidated at this time. Dilute Dexamethasone in 50 mL of saline and give slowly over 5 minutes to 10 minutes. One study showed that pretreatment with fentanyl (1.0 mcg/kg) also helped ameliorate these distressful symptoms.

## Lysine Analogs

The lysine analogs, for example, aminocaproic acid and tranexamic acid, are given to potentiate hemostasis when fibrinolysis contributes to bleeding. These drugs are associated with clinically relevant hypotension if given as a rapid IV bolus. They should be administered slowly over 10 minutes.

## Other Pearls to Avoid Common Errors Involving IV Administration in the Operating Room

- The following IV-administered products must be given through a filter: All blood products—packed red blood cells, platelets, fresh frozen plasma, cryoprecipitate, etc.
- Pressors that require dilution for administration include the following (with recommended final concentration): Phenylephrine (100 mcg/mL), ephedrine (5 mg/mL), and epinephrine (noncardiac arrest situation, 10 and 100 mcg/mL).
- Label all medications carefully!

### TAKE HOME POINTS

- One of the most important tasks for the anesthesia provider is to give dangerous drugs in a precision—this includes not only giving the correct dose of a drug, but giving it at an appropriate rate.
- Rapid administration of certain drugs can have fatal consequences.
- Do not accept information from the neurosurgeons as to the appropriate rate of phenytoin infusion—know the limiting rate yourself and personally insure it is not being exceeded. If the surgeons insist they cannot continue on with the case until the infusion is complete, then advise them they may have to adjust their expectations about how rapidly the case will proceed, but do not speed up the rate of the infusion.

The editors are personally aware of several cases with fatal outcomes due to excessively rapid administration of phenytoin. In one case, it effectively ended the career of the anesthesia provider.

- Protamine is used in the heart rooms, where it is commonly given via central access and invasive monitoring allows for close inspection of the hemodynamic effects. Somewhat more dangerous is a request by the surgeons for "50 of protamine" in a peripheral vascular case at the end of surgery, when the high-vigilance times of the case (placement and removal of the cross-clamp) are over. The request is typically made because the patient "is oozy" and so that the surgeons can close. Often the anesthesia provider is requested to give it via a peripheral IV.
- The key to controlling the rate of potassium chloride infusion is to have a policy to always use an infusion pump (NOT just an infusion set with a piece of tape over the Cair clamp).
  - Dexamethasone, even in the doses given for postoperative nausea and vomiting, can cause distressing perineal pain and pruritis if not diluted in 50 mL of saline and given over 5 to 10 minutes. Pretreatment with fentanyl may also help alleviate the symptoms.
  - Despacito doesn't apply only to the pop song. Always administer IV drugs carefully and with thought. Unless you are intimately familiar with a medication or other IV agent, you should always take a moment to consider the rate of administration, whether it should be diluted (saline vs. $D_5W$), and whether a filter is required.

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# Ketamine—Use It Well

Catherine Marcucci, MD

In 1970, 8 years after it was first synthesized, ketamine was released for clinical use in the United States. Initially ketamine was believed to be the "ideal" anesthetic, providing amnesia, analgesia, immobility, and loss of consciousness. Shortly after its use became widespread, however, there were many reports of patients emerging from anesthesia with hallucinations and recalling vivid dreams. The discovery of "emergence reactions" led many practitioners to avoid using ketamine for routine cases. However, ketamine remains an important tool in the anesthesiologist's armamentarium, as it is a versatile drug that can be given by almost any route and can provide analgesia, sedation, or general anesthesia depending on the dose administered.

Originally, ketamine was indicated as an anesthetic as well as an analgesic for cardiac surgery, trauma, obstetric analgesia, and for dressing changes in burns patients. Ketamine is different from other anesthetics in that it induces a state of dissociate anesthesia, whereby higher centers in the brain are unable to perceive auditory, visual, or painful stimuli. There is a dose-related loss of consciousness and profound analgesia. Patients' eyes remain open and they often maintain reflexes, although corneal, cough, and swallow reflexes cannot be assumed to be protective. In addition, patients have anterograde amnesia and have no recall of surgical procedures. There is a rapid onset of action, as the drug crosses the blood–brain barrier quickly secondary to low molecular weight, high lipid solubility, and a $pK_a$ near physiologic pH. Following intravenous (IV) administration, onset is seen in 30 seconds, with peak action in 60 seconds. The anesthetic effects of ketamine following a usual induction dose (1 to 2 mg/kg) remain for 10 to 15 minutes only. Drug plasma levels required for anesthesia and amnesia are 0.7 to 2.2 mcg/mL, with awakening occurring at levels of 0.5 mcg/mL. Although the anesthetic duration of action of ketamine is short, the analgesic effects last much longer, as a plasma level of only 0.1 mcg/mL is required for analgesic effects to be seen.

Ketamine interacts with N-methyl-D-aspartate (NMDA), opioid, nicotinic, muscarinic, and calcium-channel receptors. It is the antagonistic action at NMDA

receptors that produces the majority of ketamine's effects including analgesia, amnesia, and the psychotomimetic side effects. It also has effects on both central and spinal opioid receptors, with μ-receptors contributing to analgesia and κ-receptors to the psychomimetic effects. On a larger scale, ketamine leads to inhibition of thalamocortical pathways and stimulation of the limbic system.

Ketamine acts differently from other anesthetic drugs in relation to both the respiratory and cardiac systems. Ketamine does not depress respiration unless it is given in a large rapid bolus, and $CO_2$ responsiveness is maintained at or close to normal levels. The major respiratory advantage of ketamine is that it causes profound bronchodilation, to the same degree as inhalation agents. This makes ketamine an excellent choice of induction agent in asthmatic patients. It has even been used to treat refractory cases of status asthmaticus.

Unlike other anesthetic agents, ketamine does not depress the cardiac system. On induction with ketamine, increases in the heart rate, blood pressure, and cardiac output are seen. The mechanism of the cardiovascular effects is sympathetic stimulation and inhibition of both intraneuronal and extraneuronal uptake of catecholamines. Because it is indirect stimulation that leads to these effects, in the catecholamine-depleted patient, ketamine can have the opposite effect, as the drug also has a direct myocardial depressant effect that is normally masked by its sympathetic activity. Ketamine's effects on the heart lead to an increase in cardiac oxygen consumption, thus making it a poor choice for patients with ischemic cardiac disease. Patients with pulmonary hypertension are also poor candidates for ketamine, as the drug causes a greater increase in pulmonary vascular resistance than systemic vascular resistance.

A variety of patients can benefit from the use of ketamine as an induction agent, especially ASA 4 patients with respiratory and cardiac dysfunction, excluding cardiac ischemia. The bronchodilating effects of ketamine make it particularly helpful for patients with severe bronchospastic disease. The other niche where ketamine has been found to be interesting is with patients with hemodynamic compromise secondary to hypovolemia or cardiomyopathy. This includes such diagnoses as sepsis, trauma, cardiac tamponade, and restrictive pericarditis. The only caveat is that if these patients are catecholamine-depleted, the direct myocardial depressant effects may be seen. In tamponade, the benefit of ketamine is that it maintains the heart rate and right atrial filling pressures through its sympathetic stimulation. Patients who require frequent, brief procedures, such as burn patients undergoing dressing changes, can benefit from the use of ketamine as a sedative, because subanesthetic doses can be used with good analgesia and rapid return to normal function. It can be used as an adjunct to regional anesthesia, as a sedative prior to painful blocks, or to position patients already in pain. The main advantage is the profound analgesia without respiratory depression or hypotension.

Because of these properties, ketamine is useful in emergency medicine, war zones, entrapment situations, and high-altitude anesthesia.

Anesthesiologists are providing anesthesia at more locations outside of the operating room (OR) and ketamine plays an important role in the management of these patients. It is particularly useful in the emergency department because of its lack of respiratory and cardiac depression as well as its ability to be administered intramuscularly. A combination of ketamine and midazolam administered intramuscularly can provide excellent sedation for an uncooperative or combative patient who requires sutures of manipulation of a displaced fracture. It also has a role in airway management in the ED as you can adequately sedate a patient for intubation while maintaining spontaneous respiration.

Pediatric anesthesia includes another subset of patients who benefit from the use of ketamine. Intramuscular ketamine (7 to 9 mg/kg) remains in use for induction of anesthesia in uncooperative pediatric patients. Children with neuromuscular disorders also benefit from the use of ketamine as a maintenance agent, as volatile agents should be avoided in these children, who are at increased risk of malignant hyperthermia. Children with congenital heart defects leading to right-to-left shunt do well with ketamine as an induction agent for cardiac surgery, as it increases systemic vascular resistance and does not reverse the shunt. Finally, ketamine is useful for pediatric sedation, as it produces analgesia and sedation with a low incidence of complications. Emergence reactions are much less common in the pediatric population than in adults.

A more controversial area for ketamine is its use in neurosurgical patients. It had previously been thought that ketamine increased intracranial pressure and cerebral blood flow and was therefore contraindicated in patients at risk for elevated intracranial pressure. However, recent studies have shown that if benzodiazepines are given with ketamine and normocapnia is maintained, there is no elevation in intracranial pressure and so ketamine may have a role in neurosurgery. In addition, blockade of NMDA receptors may be neuroprotective, as it can decrease cell destruction and necrosis following cerebral ischemia. The role of ketamine in neurosurgery has not yet been decided and further research will determine its utility.

Recently, ketamine has received much attention for its use as an analgesic. It has been used as an adjunct in both acute postoperative pain management as well as in chronic pain, including both neuropathic and refractory cancer pain. The analgesic effects of ketamine are due to several mechanisms. The primary mechanism is NMDA-receptor antagonism leading to suppression of pain transmission to higher centers in the brain. Ketamine also prevents the development of tolerance to acute opioid administration and development of increased pain sensitivity secondary to opioid-induced hyperalgesia by its NMDA antagonism. By this mechanism it also prevents the

"windup" phenomenon, which is an increase in the dorsal horn activity due to repetitive and constant C-fiber stimulation. There is some evidence that ketamine also acts directly on opioid receptors in the brain and spinal cord, contributing to its analgesic effect.

For postoperative pain control, ketamine can be given preincision, postincision, or as a part of the postoperative pain regimen. Subanesthetic doses of ketamine (0.1 to 0.3 mg/kg) produce analgesia and the analgesic effects of an induction dose of ketamine are seen for several hours following an initial bolus dose. The goal of pre-emptive analgesia is to decrease postoperative pain by interrupting nociceptive pathways. NMDA receptors are responsible for pain memory and "windup," so ketamine, an NMDA antagonist, can prevent the massive nociceptive afferent impulses from reaching the brain. However, at the present time there is some controversy regarding the efficacy of pre-emptive ketamine and whether it is able to reduce total opioid requirements postoperatively. If it is given intraoperatively, it has been shown that ketamine is a much more effective analgesic when given as an infusion rather than as a single-bolus dose at the time of induction. Anesthesia providers who have a lot of sedation cases report that a ketamine infusion coupled with a low- to moderate-dose propofol infusion (known sometimes in the vernacular as "P–K anesthesia") has good efficacy in a wide range of surgical cases. Postoperatively, ketamine has been added to patient-controlled analgesic (PCAs) (1 to 2 mcg/kg/hr) and has been shown to decrease the total amount of morphine required as well as to decrease side effects.

Ketamine has been used as an additive with local anesthetics for epidural or caudal use and patients receiving ketamine in this form require less postoperative opioid than those receiving only local anesthetics. However, racemic ketamine is not preservative free, and the preservative benzethonium chloride may be neurotoxic. S(+)-ketamine is an isolated stereoisomer that is preservative free and shows potential for future neuraxial use. The FDA just granted approval of esketamine. In Europe, S(+)-ketamine has gained in popularity and is a more potent anesthetic associated with more rapid emergence and a lower incidence of emergence reactions.

The newest role for ketamine appears to be in the field of psychiatry rather than anesthesia. It has been used with much success at treating severe depression and bipolar disorder both alone and in combination with ECT. A ketamine nasal spray for depression is now available.

Although it has many advantageous properties, no drug is without its adverse reactions. Ketamine has a **fairly notorious side-effect profile**, which may lead to hesitance in using this drug. The emergence reactions seen with ketamine include visual, auditory, and proprioceptive illusions that can illicit fear or excitement in patients. The same is true of the duration of ketamine sedation. An illustrative clinical anecdote was

related by one of the certified registered nurse anesthetist (CRNA) advisers to this book: The anesthetist was using ketamine as a partial induction agent, and just as the patient lost consciousness, one of the OR staff mentioned that he had killed a large black snake in his yard that morning. On emergence, the patient related that he had had vivid and severely unpleasant "dreams" under anesthesia about black snakes. The anesthetist now uses the power of suggestion in a positive way before the administration of ketamine—she tells her patients they may have vivid dreams and asks them to imagine their favorite or a very pleasant "brightly colored place," for example, a sunny tropical beach or brilliant fall foliage. She also requests that there be no excessive chatter or loud noises at induction.

**It is also well recognized that the concomitant use of benzodiazepines reduces the risk of emergence reactions, and virtually all practitioners who use ketamine preadminister a benzodiazepine, almost always midazolam. The amount of midazolam given before administration of ketamine varies based on individual practice, but most practitioners will give the amount that will produce moderate sedation without respiratory depression. One of the editors recently had ketamine sedation, without a benzodiazepine, for reduction of a badly broken ankle in the ED of a community hospital. The experience was not pleasant. "Emergence" from ketamine felt like walking through a funhouse full of distorted mirrors but the previous minutes would have been extremely distressing had the patient not understood (at the professional level) why she was tobogganing through hyperspace wrapped in a red shroud.**

Ketamine also causes profuse salivation in some patients, which can be a problem in the unprotected airway with the possibilities of laryngospasm and aspirations. It is recommended to pretreat these patients with an antisialagogue such as glycopyrrolate. Atropine is to be avoided, as it can cause an increased risk of delirium on emergence. However, with appropriate use and proper patient selection, ketamine has proven to be beneficial for a variety of procedures and patient populations.

## TAKE HOME POINTS

- Although ketamine went through a period of "unpopularity," it is actually a valuable drug that every anesthesia provider should be familiar with and comfortable using.
- It can be given by a number of routes and acts at a number of receptors. It can be used for sedation, amnesia, anesthesia, and pain relief.
- Consider it especially in cases when sedation/anesthesia is needed for short periods of intense surgical or procedural stimulus, such as dressing changes, burn treatments, or removal of K-wires.
- It is valuable as an adjunctive agent in both general anesthetic and sedation cases.

- Actively manage the potential side effects, particularly the possibilities of hallucinations—reassure and discuss beforehand with the patient, always give a benzodiazepine, and ensure a quiet, calm anesthetizing location. Assure the patient that the hallucinations will be short-lived and that she will be constantly monitored.
- Contraindications to ketamine include:
  - Elevated ICP
  - Open-eye injury—ketamine increases intra-ocular pressure
  - As sole anesthetic in ischemic cardiac disease
  - Vascular aneurysm—don't want sudden change in arterial pressure
  - Psychiatric disorders like schizophrenia
  - History of adverse reaction to ketamine or phencyclidine
  - If postop delirium could be from other cause—delirium tremens, head trauma
  - Factors that increase risk of delirium include:
  - Age >16 years
  - Dose >2 mg/kg
  - Pre-existing personality problems

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# TIVA—What You Need to Understand to Do It Well

Jeff E. Mandel, MD MS

Total intravenous anesthesia (TIVA) is a technique finding increasing acceptance in modern anesthesia practice for diverse reasons. Whether it is better neurocognitive outcomes, less contamination of the environment, use of high-frequency jet ventilation, improved visualization during sinus surgery, or a host of other reasons, practitioners are increasingly motivated to embrace this technique. It is assumed that the reader has already determined the motivating factors, and the purpose of this chapter is to explain some practical points for managing these anesthetics.

There are several areas that require mastery:

) Pharmacokinetics
) Pharmacodynamics
) Delivery systems

## Pharmacokinetics

While a rich understanding of inhalational pharmacokinetics is certainly useful, inhalational agents are simpler for several reasons—during induction and maintenance the vaporizer setting is the upper limit on the alveolar concentration, elimination is entirely due to ventilation, and monitoring the alveolar concentration gives insight into the process. Intravenous agents are delivered at concentrations far beyond the intended blood concentration, elimination is by metabolic clearance, and we have no practical bedside monitors of drug concentration. Fortunately, it is possible to measure all of the clinically relevant drugs in a laboratory setting making it possible to develop pharmacokinetic models. The models are not perfect, but can provide us with clinical insights. We will employ several published models to explore what makes TIVA work well (or poorly).

Most anesthetic drugs are adequately described by two- or three-compartment models; a central compartment and one or two peripheral compartments. There is no need to give these compartment anatomic names, fast and slow will suffice. These

compartments are typically large pools that can hide drugs through redistribution, but are not the sites of drug action. We typically add an effect site, a compartment of negligible volume and a time constant that explains the observed time to peak effect. This is also not a real anatomic compartment, just a modeling convenience. What is real is that anesthetic drugs vary in three important areas:

) Time to peak effect
) Redistribution
) Elimination

## Time to Peak Effect

A short time to peak effect makes a drug a good induction agent. Anesthesiologists like drugs that work in the "arm–brain time," because we like holding syringes in our hands, as if we can somehow feel the backpressure of the central nervous system against our thumb. With TIVA, the drug will be delivered from an infusion pump, and it is possible to match the time to peak effect of two drugs that differ in this regard, as shown in Figure 71.1. If we want to match the onset of propofol (time to peak effect 96 seconds) to sufentanil (time to peak effect 5 minutes), delivering 131 mg over 4 minutes followed by 307 μg/kg/min will achieve this. We cannot shorten the time to peak effect of a slow drug with a pump, although we can shorten the time to a specified clinical effect by giving an overdose and dealing with the consequences. Using combinations of drugs with similar times to peak effect (e.g., midazolam + fentanyl, propofol + remifentanil) simplifies matters.

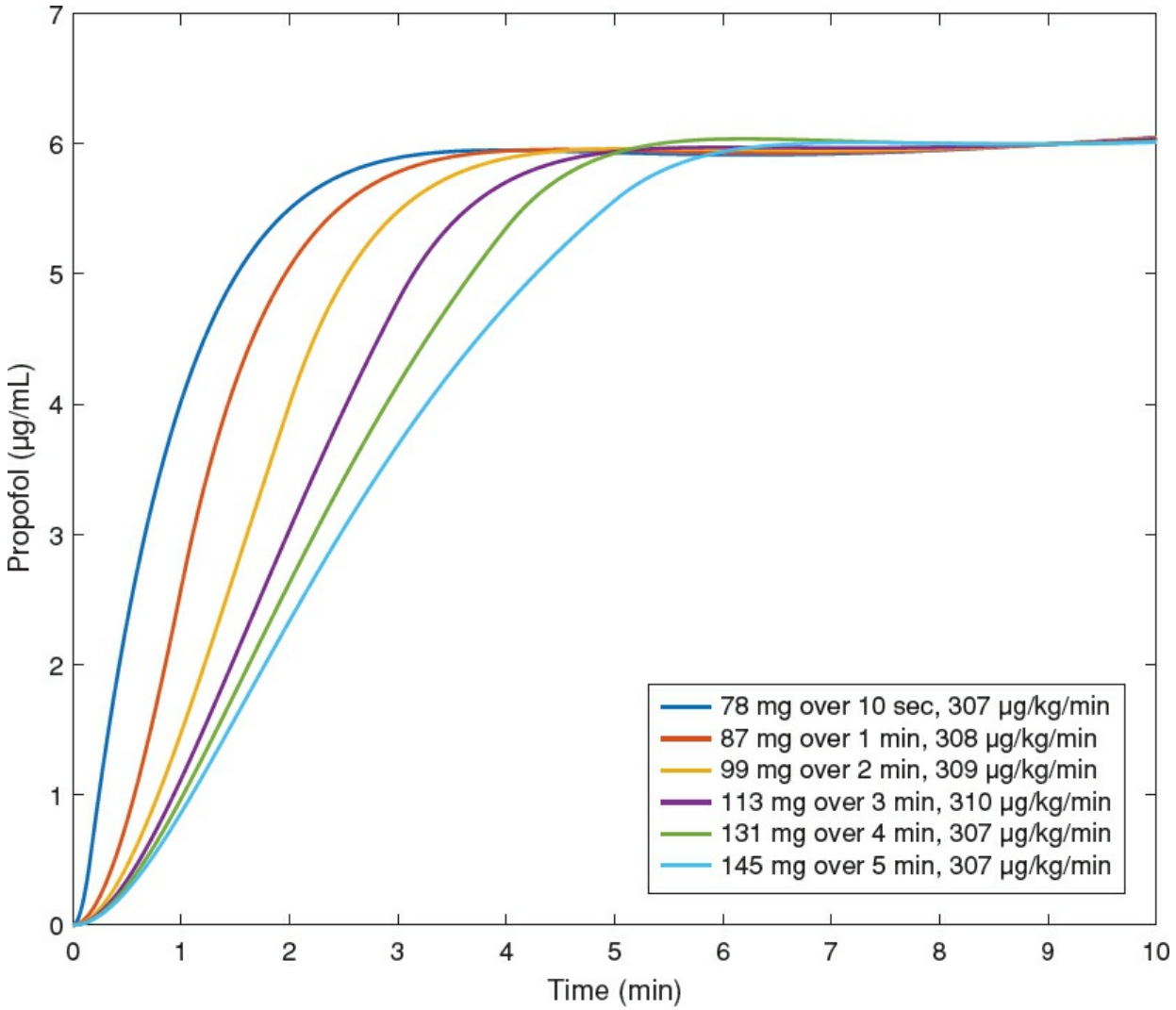


**Figure 71.1.** Simulation of the effect site concentration of propofol when giving a bolus and infusion designed to achieve a target concentration of 6 µg/mL for bolus durations ranging from 10 seconds to 5 minutes.

## Redistribution

Most drugs redistribute into peripheral compartments following a bolus. A drug that is highly redistributed will appear to be short-acting after a single bolus, but if we want to maintain a steady clinical effect, redistribution complicates matters, as we must give a loading dose to fill the peripheral compartments so that a constant infusion yields a constant plasma concentration. The time constant of the peripheral compartments is also an issue; the longer the time constant the longer the time we are in the loading phase. In addition, we can have multiple compartments with different time constants. This is demonstrated in Figure 71.2 (left panel). In the left panel, it appears as if all the drugs come into steady state by the end of 90 minutes. The right panel illustrates that from 2 to 8 hours steady state is maintained for remifentanil and alfentanil, but for propofol and sufentanil, levels creep up slowly. Fentanyl continues to increase linearly with time

over the 6 hours (and will do so for about 2 days). While we can employ pump loading strategies during induction to control the overshoot while filling peripheral compartments, drugs such as remifentanil require almost no effort to obtain stable control compared to drugs like fentanyl.

There are times when it is necessary to deepen TIVA, typically due to increases in surgical stimulation. A frequent response is to grab a syringe of propofol and administer a bolus. There are two reasons not to do this. First, inadequate analgesia is better addressed by an increment in both propofol and remifentanil. Second, the bolus required to smoothly transition to a new effect site concentration is much less than is typically delivered from a 20 mL syringe. This is depicted in Figure 71.2 (right panel). Here we have determined the boluses necessary to produce a smooth transition to a 10% increase in effect site concentration of propofol and remifentanil after 1 hour of maintenance. The values of the boluses necessary are small. Expressed in terms of the increment in infusion rates, they represent 7.6 and 7 minutes, respectively of this increment. Thus, if we are infusing 50 µg/kg/min of propofol and want to change the rate to 60 µg/kg/min (a 10 µg/kg/min increment), a bolus of 76 µg/kg will suffice. In a 70-kg patient, that is 5.3 mg. A hand bolus will typically exceed this by a factor of 4 to 8, resulting in considerable overshoot. During this overshoot, we do not know if the new infusion rate has solved the problem or not; we only find out 10 minutes down the road.

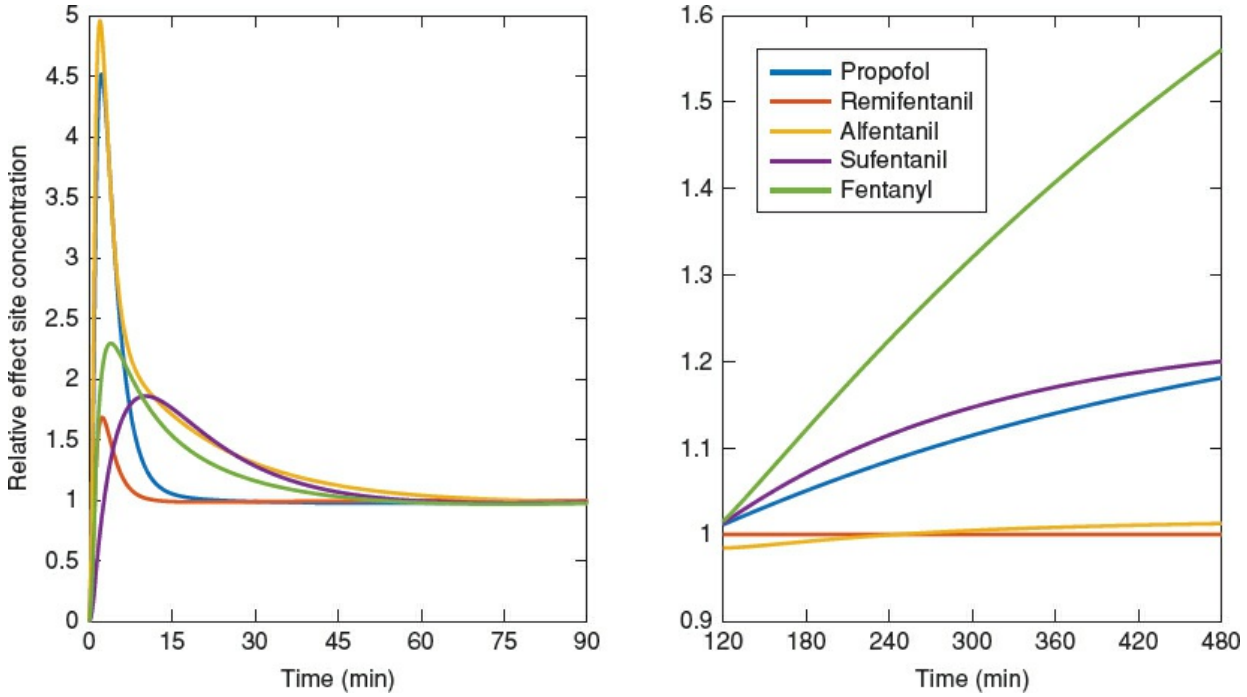


**Figure 71.2. Left:** Simulation of the relative effect site concentrations for propofol, remifentanil, alfentanil, sufentanil, and fentanyl after an initial bolus and constant infusion selected to provide a stable maintenance phase. **Right:** A small bolus and increased infusion designed to produce a 10% increment without overshoot in effect site concentrations of propofol and remifentanil after 1 hour of maintenance.

## Elimination

As we approach steady state with an infusion, the peripheral compartments come into equilibrium with the plasma, and this volume of drug must diffuse back into the plasma in order to undergo metabolic clearance. The shape of the biexponential elimination curve changes as the peripheral compartments fill. This shape is hard to capture with a single number, which led to the concept of the context-sensitive half-life. The context is the time-weighted administration history, not the duration of infusion. The half-life is the time required for the effect site concentration to drop 50%, which is only relevant if a 50% reduction achieves your clinical goal. Thus, any simple formula that says "turn off the drug x% of the duration of administration" is likely to be wrong. This is demonstrated in Figure 71.3. Applying the infusion sequences developed in Figure 71.2, we stop the infusion at various times between 30 minutes and 6 hours and determine the time required for a 50% drop in effect site concentration, as depicted in the left panel. The right panel plots the half-life versus the duration of the infusion. We can see that drugs such as fentanyl are poorly suited to prolonged infusion, as the half-life increases linearly with increasing duration (and approaches an asymptote of 5 hours after 2 days). Conversely, remifentanil has almost no context sensitivity, and propofol is far less context sensitive than alfentanil and sufentanil. Turning off a context sensitive drug in anticipation of the end of a procedure only works if we are above the concentration required to prevent a response to surgical stimulus for the entire time we have had the infusion off. We will examine this further in the next section.

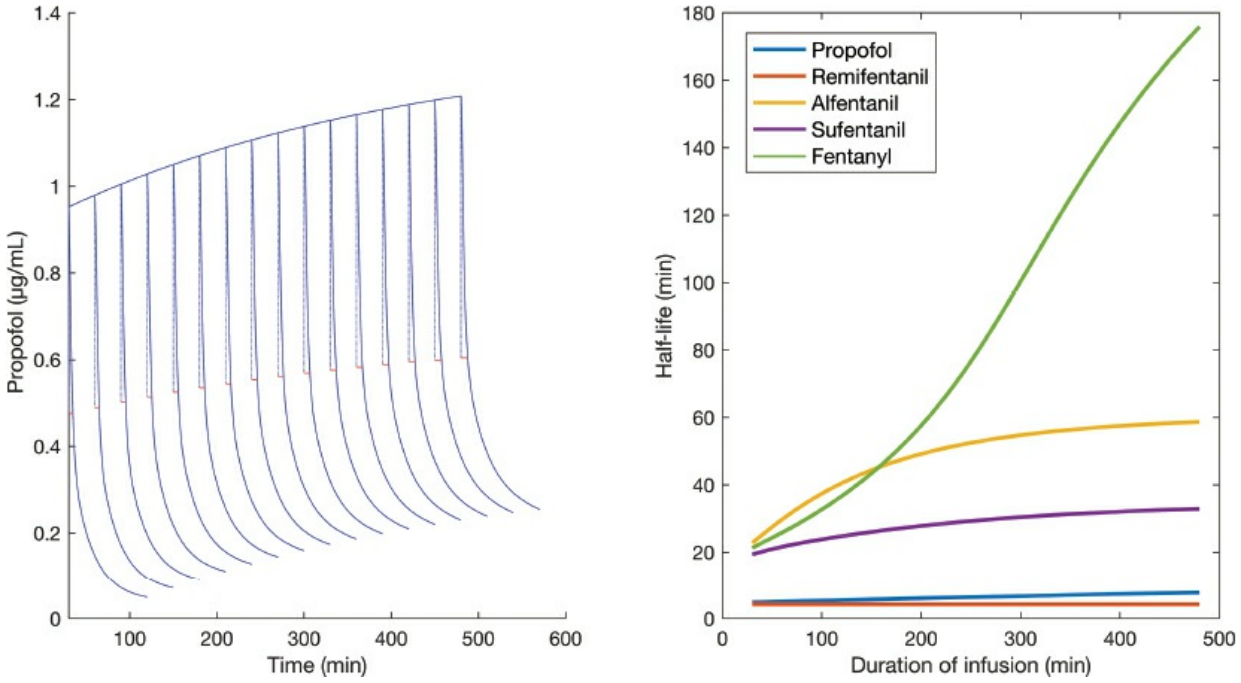


**Figure 71.3. Left panel:** Trajectory of the effect site concentration for propofol after stopping the infusion after increasing durations. The vertical dashed line indicates a 50% drop. The length of the

horizontal red line is the half-life. **Right panel:** Half-life versus infusion duration for a number of drugs.

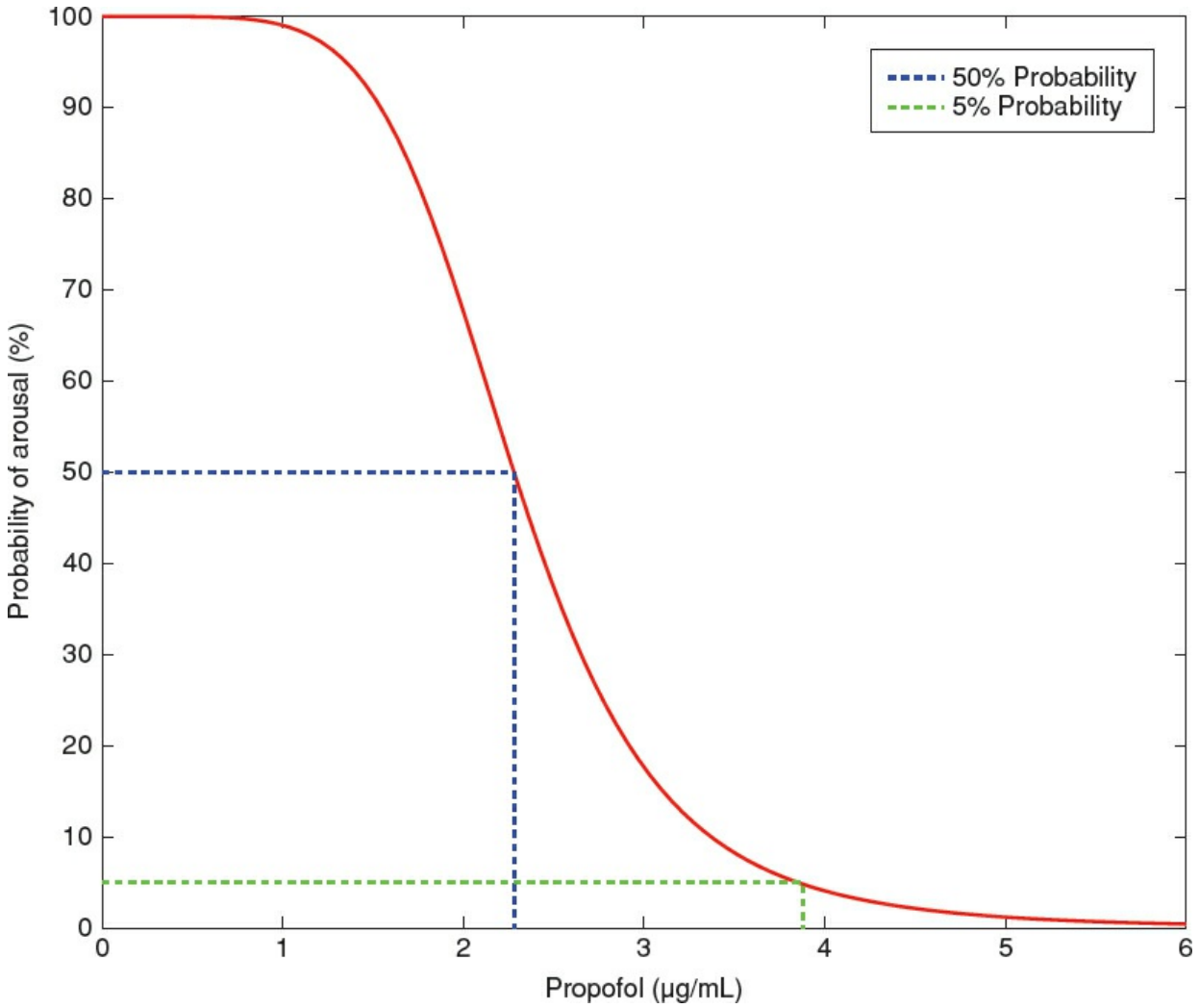


**Figure 71.4.** Probability of return of consciousness versus propofol effect site concentration.

## Pharmacodynamics

Understanding the pharmacodynamics of the inhaled anesthetics is simple, as there is so little variability in MAC within the population. Not so with intravenous agents; there is considerable variability in the effect site concentration that creates unconsciousness and immobility across the population. This is illustrated in Figure 71.4, which depicts the probability of return of consciousness as the propofol concentration drops from 6 µg/mL to 0. We quickly see the problem posed in the previous section—if we want to be assured that very few patients will be awake 20 minutes after discontinuing a propofol infusion, having the propofol effect site concentration at 3.8 µg/mL will not achieve this, as 5% of the population will already be awake. On the other hand, if we knew that the particular patient was the median patient, having the effect site concentration just above 2.3 µg/mL is an excellent strategy, as we would achieve emergence rapidly following

discontinuation of the infusion. We have demonstrated this approach in simulation.

Another important effect is drug synergy. For drugs acting on different loci, we can describe a line of substitution of one drug for another at constant clinical effect. This is depicted in Figure 71.5. The blue line is comprised of all combinations of propofol and alfentanil at which 50% of patients emerge from anesthesia, the red line is comprised of all combinations of propofol and alfentanil at which 50% of patients move in response to surgical stimulus. If we know we are dealing with the median patient, we can obtain immobility at 2.3 µg/mL propofol if we have enough opioid. The shorter the half-life of the opioid relative to that of propofol, the more we can exploit this synergy to shorten emergence. If we add fentanyl to propofol, we cannot add much before the offset of the fentanyl overwhelms the offset of the propofol, but with remifentanil, we can add a considerable amount and significantly accelerate emergence. Vuyk described this in an elegant in silico study.

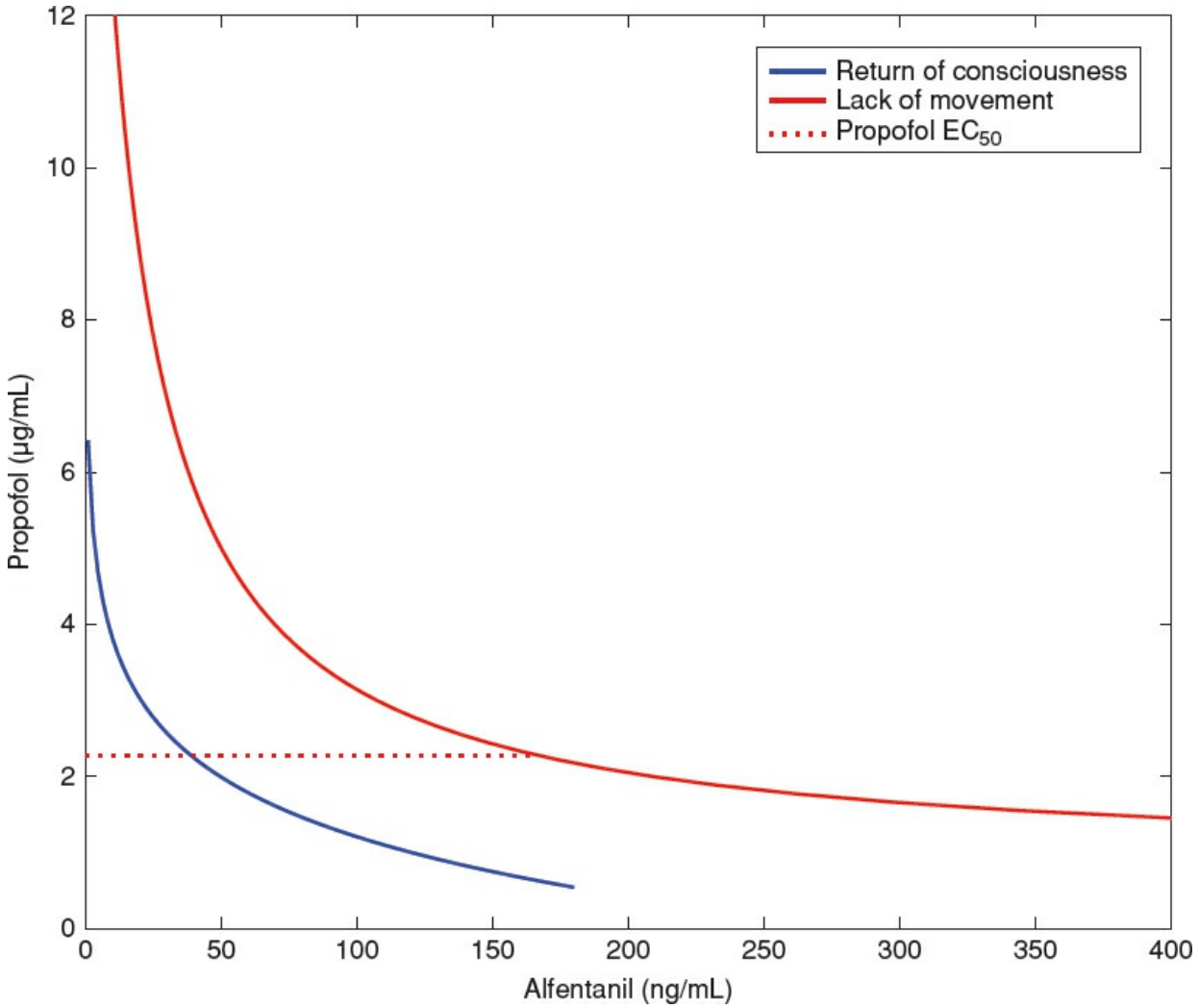


**Figure 71.5.** Fifty percent isoboles for return of consciousness (blue) and lack of movement in response to surgical stimulation for combinations of propofol and alfentanil.

## Infusion Systems

TIVA requires the use of infusion pumps and systems of tubing. These systems can introduce sources of error into the delivery process. In particular, most infusion pumps perform poorly during the initial infusion as all mechanical elements come into tension, particularly with syringe pumps. If an accurate assessment of the initial loading dose of a drug is needed, it is best to at least partially prime the system using the pump, rather than placing a fully primed syringe and tubing set into the pump and pressing start. A more complete description of the issues surrounding infusion pumps can be found in an article by the author.

Common volume is the volume that a drug must traverse before entering the body. When infusing more than one drug, or when a carrier flow is used, any change in drug administration is delayed by the time it takes to traverse the dead volume. As the infusion rate of any fluid comingling in the common volume changes, biphasic transient changes in administration rates of all drugs can be seen. The larger the common volume, the longer the duration of this effect. An excellent description of this problem can be found in an article by Lovich and Peterfreund. Several important points to observe is to avoid any volume between the point of mixing of multiple infusions and the vein, avoid high concentrations of drugs, and avoid carrier lines in the common path.

### TAKE HOME POINTS

- Total untravenous anesthesia differs from traditional anesthesia in that the ability to initiate, maintain, and terminate the anesthetic requires some understanding of pharmacokinetics and pharmacodynamics.
- Given the wide variability in these properties, simple rules that apply to all patients are not easily formulated.
- TIVA can be a very stable anesthetic within a narrow range around optimal infusion rates, but can be quite unstable when "fighting the stick," in aeronautical parlance.
- It is best to think 5 minutes out, rather than expecting drugs to work in less than their time to peak effect. Hopefully, this chapter will be useful in avoiding some of the common errors in TIVA.

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# Dexmedetomidine: Is There Such a Thing as a Free Lunch?

Martin Anixter, MD and Tetsuro Sakai, MD PhD MHA FASA

Sedative-hypnotic and analgesic agents (benzodiazepines, propofol, and opioids) form an integral part of anesthesia to provide patients' comfort and safety in the operating room (OR) and the intensive care unit (ICU). $\alpha_2$-adrenergic receptor agonists are being increasingly used in the perioperative and critical care settings for their sedative, analgesic, and sympatholytic effects.

## What is Dexmedetomidine?

Dexmedetomidine (Precedex™; Abbott Labs, Abbott Park, IL, USA) is a selective $\alpha_2$-adrenergic receptor agonist, where specificity for the $\alpha_2$-adrenergic receptor versus $\alpha_1$-adrenergic receptor is 1,622:1. Compared to other $\alpha_2$-adrenergic agonists such as clonidine, dexmedetomidine is eight times more specific and has a shorter half-life (2 hours for intravenous [IV] dexmedetomidine vs. 8 to 12 hours for peroral clonidine).

## How Does Dexmedetomidine Work?

Dexmedetomidine stimulates $\alpha_2$-adrenoreceptors in the locus caeruleus of the brainstem to provide sedation. It also provides analgesia by stimulating $\alpha_2$-adrenoreceptor in the central and peripheral nervous systems. Dexmedetomidine causes sympatholysis via central and peripheral mechanisms. Following IV administration, dexmedetomidine undergoes rapid redistribution, with a distribution half-life of 6 minutes and an elimination half-life of 2 hours. Dexmedetomidine exhibits linear kinetics in the dosing range of 0.2 to 0.7 mcg/kg/hr when administered through IV infusion for 24 hours. Dexmedetomidine is 94% protein bound and undergoes nearly complete biotransformation in the liver to inactive metabolites that are excreted in the urine.

## Potential Benefits of Dexmedetomidine

During a continuous infusion within its therapeutic level, dexmedetomidine provides

sedation where patients may be arousable to command, provides some direct analgesia, synergizes with other sedatives and analgesics, and produces minimal depression of ventilation. Dexmedetomidine has no pharmacokinetic or cytochrome P450 enzyme drug–drug interactions.

## Complications/Contraindications

Hypotension and bradycardia are the most frequently observed adverse events associated with dexmedetomidine. Even decreases in the heart rate have been seen in patients with transplanted hearts. As the net effect of $\alpha_2$-adrenergic agonists is sympatholytic, caution should be exercised in patients with pre-existing severe bradycardia disorders, or in patients in whom sympathetic tone is necessary for hemodynamic stability. Case reports of bradycardia and sinus arrest have been associated with dexmedetomidine administration, both in initial studies with volunteers, during coadministration of dexmedetomidine with other provagal drugs/stimuli, and when large doses are used. A case report of persistent bradycardia occurred following high-dose (2 mcg/kg) intranasal administration in a pediatric patient for a sedation case. Hypertension is associated with high plasma levels of dexmedetomidine, such as during a rapid loading dose or IV bolus, which cause peripheral vasoconstriction via activation of postsynaptic $\alpha_2$-adrenergic receptors.

Recent clinical studies, however, demonstrated more reliable control of heart rate and blood pressure in patients undergoing surgery with appropriate doses of dexmedetomidine. Dose reduction should be considered in patients with impaired liver and renal function. Dexmedetomidine is contraindicated in patients with a known hypersensitivity to the drug, which has not been reported so far.

## FDA-Approved Uses

In 1999, dexmedetomidine was approved by the U.S. Food and Drug Administration (FDA) for sedation of adult patients who are intubated and mechanically ventilated in the intensive care setting. Dexmedetomidine should be administered by continuous infusion not to exceed 24 hours. In 2008, the indication for sedation prior to and during procedures for nonintubated patients was added.

## How to Administer Dexmedetomidine

Dexmedetomidine is supplied in 2-mL vials each containing 100 mcg of drug/mL (200 mcg total) and should be diluted with 48 mL of sterile water or 0.9% sodium chloride to a final concentration of 4 mcg/mL. Dexmedetomidine is recommended to be administered as a loading dose of 1 mcg/kg over 10 to 20 minutes, followed by a

maintenance infusion of 0.2 to 0.7 mcg/kg/hr, titrated to the desired sedation scale.

## Clinical Applications of Dexmedetomidine

**Intensive Care Unit:** Because of its nonopioid mechanism of sedation, analgesic properties, and lack of respiratory depression, dexmedetomidine has been used in the critical care setting for sedation. It is associated with hypotension and bradycardia, which may be treated with fluid bolus, decreasing infusion rates, and rarely discontinuing the drug. It is not necessary to discontinue dexmedetomidine infusion before extubation. The use of dexmedetomidine is not limited to the ICU, and a growing body of literature has described the effectiveness of the drug in perioperative settings.

**Operating Room:** Compared to placebo or propofol infusion, dexmedetomidine infusion was reported to provide more stable hemodynamics for patients who underwent cardiac and vascular surgeries. It is increasingly being shown to reduce mortality in these settings. Dexmedetomidine seems to reduce the adrenergic response to laryngoscopy, intubation, and surgery. It potentiates the anesthetic effects of varieties of intraoperative anesthetic drugs. This anesthetic-sparing effect of dexmedetomidine can be translated into a more rapid recovery from anesthesia. Dexmedetomidine may also be useful as an anesthetic adjunct in patients at risk for postoperative respiratory depression or airway obstruction, such as morbidly obese patients, in whom the opioid-sparing effects of dexmedetomidine have proven extremely useful. Dexmedetomidine has been used as a single-agent sedative along with topical anesthesia for awake fiber-optic intubation. It has been used as an adjunct in monitored anesthesia care. Some studies have demonstrated the effective use of dexmedetomidine in awake craniotomy, or even as a sole anesthetic for minor procedures.

**Pediatrics:** Dexmedetomidine has gained significant attention for the treatment of emergence delirium, which is a frequent phenomenon in children recovering from general anesthesia. Perioperative dexmedetomidine has been shown to reduce the incidence of emergence delirium and is also useful for treatment. Both continuous infusions and bolus doses have been studied and both treatment options have not shown any significant increase in prolonging time to extubation or time to discharge from the postanesthesia recovery unit. Non-IV administration (intramuscular, intranasal, and buccal) of the drug has also been studied in this population. Dexmedetomidine has also become a viable option for pediatric ICU sedation, much as in the adult population. This has allowed avoiding the prolonged use of propofol for sedation, minimizing the possibilities of “propofol infusion syndrome.” Intriguingly, it may have a role in attenuating the potential neurotoxicity of anesthetic agents, although this work is still preliminary. Dexmedetomidine is not currently approved by the FDA for use in the pediatric population.

## Clinical Controversy

Many investigators have demonstrated a variety of off-label clinical applications of dexmedetomidine as described above. A few studies also suggest caution in the usage of dexmedetomidine. The provagal effect of dexmedetomidine was demonstrated by Ebert and associates, with augmentation of baroreceptor response to phenylephrine and preservation of baroreceptor response to nitroprusside. This "provagal" effect of dexmedetomidine was considered to be a contributory factor in the cardiac arrest of an adult patient, reported by Ingersoll-Weng and others, who underwent sternotomy with a thoracic epidural anesthesia and preoperative pyridostigmine. The recent case report by Patel et al. reinforces this idea.

Delayed recovery can be a problem with dexmedetomidine. Jalowiecki and colleagues counseled against the use of dexmedetomidine as a sole agent for procedural sedation, in light of hemodynamic instability and the need for prolonged recovery. Koroglu and associates found a similar delayed emergence in the use of dexmedetomidine in children for MRI sedation compared to propofol.

There is significant synergism of the sedative effect of opioids with dexmedetomidine. Therefore, one should be cautious when giving dexmedetomidine in the presence of opioids, which can result in delayed emergence. There are case reports of polyuria after dexmedetomidine infusion, as it can reduce the sensitivity and release of antidiuretic hormone. There have been reports of withdrawal symptoms in patients after long infusions, consisting of agitation, nausea/vomiting, and tachycardia/hypertension. In practice terms, the use of dexmedetomidine may be cumbersome because of the recommendation of a loading dose and continuous infusion.

Dexmedetomidine is currently approved by the FDA only for sedation in mechanically ventilated adult patients who are being monitored in the ICU and periprocedural sedation for nonintubated adults. Large prospective clinical studies are needed to further elucidate and confirm the effectiveness of the off-label uses of dexmedetomidine.

## TAKE HOME POINTS

- Dexmedetomidine, a selective $\alpha_2$-adrenergic receptor agonist, has sympatholytic properties, directly provides sedation and analgesia, and reduces the use of other sedative/ analgesic agents, without respiratory depression.
- Dexmedetomidine is recommended to be given as a loading dose of 1 mcg/kg over 10 to 20 minutes, followed by a maintenance infusion of 0.2 to 0.7 mcg/kg/hr for a total duration of not more than 24 hours.
- Dexmedetomidine is currently approved for intubated and mechanically ventilated

adult patients in the ICU, as well as periprocedural sedation for nonintubated patients. However, it has demonstrated its effectiveness in other settings.

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# Consider Chloroprocaine in Emergency Situations—It Is a Rapid-Onset Local Anesthetic With Low Systemic Toxicity

Brandon Michael Togioka, MD, Josh Zimmerman, MD FASE, and Randal O. Dull, MD PhD

2-Chloroprocaine is an ester-type local anesthetic with rapid onset and a large therapeutic window (the ratio between the effective concentration and toxic concentration), which minimizes its risk for toxicity. It has the shortest duration of action among commonly used local anesthetics. It was introduced to the medical community in 1951 when a journal article described successful skin wheals, regional anesthesia, and spinal nerve blocks. Despite its initial description as a spinal anesthetic, concerns over toxicity when administered directly into the intrathecal space have caused 2-chloroprocaine to find its greatest use in labor epidurals in situations when rapid anesthesia is needed.

## Chemical Structure

Local anesthetics are classified as esters or amides. All local anesthetics consist of three parts: a lipophilic benzene ring, an intermediate bond, and a hydrophilic group. The intermediate bond in ester local anesthetics is an ester linkage and the intermediate bond in amide local anesthetics is an amide linkage. 2-Chloroprocaine is an ester local anesthetic. One can determine if a local anesthetic is an ester or an amide by looking at the generic name. Amides contain two “i” and esters only contain one “i.”

## Clinical Pharmacology

Like all local anesthetics, chloroprocaine inhibits the generation and propagation of nerve impulses through sodium channel blockade. Being an ester, 2-chloroprocaine is metabolized by plasma cholinesterases into an alcohol and para-aminobenzoic acid. Chloroprocaine is metabolized much more quickly than procaine or tetracaine, contributing to its low systemic toxicity. According to in vitro studies (outside the body), the plasma half-life of 2-chloroprocaine is 25 seconds in women and 43 seconds

in neonates. Conditions, such as liver disease, pre-eclampsia, or pseudocholinesterase deficiency can prolong the action of 2-chloroprocaine and increase the potential for toxicity. Remember that dibucaine number that you learned about years ago? It actually applies here. Patients with homozygous atypical plasma cholinesterase will have a low dibucaine number (20 to 30) and consequently are at increased risk of chloroprocaine toxicity.

All local anesthetics consist of a mixture of ionized and nonionized forms. The nonionized form is the part that penetrates the nerve sheath; however, once inside, some of the local anesthetic converts back to the ionized form for binding to sodium channels. Typically, the more nonionized drug that is available, the faster the onset of action. Chloroprocaine is an exception. It has one of the highest pKa's and thus is present almost exclusively in ionized form. **So how does it act so quickly?** Its fast onset of action is due to its low potential for toxicity. Because 2-chloroprocaine has low systemic toxicity, it can be administered in very high concentrations (commonly 3%); thus, deposition of a large quantity of molecules creates a diffusion gradient that overcomes the high pKa.

## Toxicity Controversy

In the 1980s, multiple articles were published describing significant neurologic sequelae (permanent paralysis, sensory deficits, anterior spinal artery syndrome, cauda equina syndrome, and arachnoiditis) after spinal administration of 2-chloroprocaine in animals and humans. It was not clear at the time whether the etiology was the local anesthetic or the sodium bisulfite preservative. A study on rats published in Anesthesiology in 2004 concluded that the toxicity was due to chloroprocaine. However, the suitability of the rat model has since been questioned as the enzyme that breaks down toxic sulfite is present in rats in concentrations 10 to 20 times that of humans. Thus, the etiology of the toxicity remains controversial. Regardless, most chloroprocaine solutions currently available are now preservative-free.

## Clinical Use

**Intrathecal Use.** As described earlier, spinal chloroprocaine was not used in the anesthesia community for several decades. Recently, studies were published describing the safe use of preservative-free intrathecal 2-chloroprocaine. These studies have shown that chloroprocaine produces a reliable block similar to lidocaine or bupivacaine with a shorter time to motor recovery, shorter time to simulated discharge, and lower risk for transient neurologic syndrome than lidocaine. Interestingly, it was noted that epinephrine should not be added to spinal chloroprocaine as most patients got a "flu-like syndrome." In summary, spinal chloroprocaine is far from the standard of

care, but there is accumulating evidence that it may be the choice anesthetic for ambulatory procedures in the future.

**Epidural Use.** Because of its low toxicity and rapid onset, chloroprocaine has been used effectively for years as an epidural anesthetic for emergent caesarean delivery. Chloroprocaine is the ideal local anesthetic in this situation because of its fast onset of action, low potential for maternal toxicity, and low potential for fetal toxicity in the setting of fetal distress (which often means fetal acidosis). A study showed that unlike lidocaine and bupivacaine, chloroprocaine does not ion trap. Ion-trapping is the idea that because fetal pH is usually less than maternal pH, toxic local anesthetics can become "trapped" in their ionized forms in fetal circulation leading to higher concentrations in the fetus. We commonly administer 15 mL of 2-chloroprocaine (3%) solution when a patient has been using their labor epidural and 20 mL of 2-chloroprocaine (3%) solution in a virgin epidural to get a T4 level for caesarean delivery. The duration of action for chloroprocaine is short, only 30 to 50 minutes. Repeated dosing is sometimes necessary. It should also be noted that chloroprocaine can affect the effectiveness of other drugs administered into the epidural space. Chloroprocaine administration has been linked to decreased efficacy of subsequently administered epidural fentanyl, bupivacaine, and morphine.

**Topical Use.** Although it is not an "on-label" use, 2-chloroprocaine provides rapid topical anesthesia for skin incisions and has even been used to help avoid general anesthesia during caesarean delivery when a neuraxial block is inadequate. This is the so called "splash block," whereby chloroprocaine is instilled into the peritoneal cavity during caesarean delivery to facilitate treatment of acute intraoperative pain. This has yet to be proven safe as there are often open venous channels around the uterus that may allow for fast systemic uptake; however, it is hypothesized to be safe because of chloroprocaine's rapid plasma clearance. A study is currently underway to determine maternal plasma concentrations of chloroprocaine when this splash block is used.

## TAKE HOME POINTS

- Chloroprocaine is an ester-type local anesthetic with a very short plasma half-life and subsequent low potential for systemic toxicity.
- Chloroprocaine has a fast onset of action and is ideal in situations when rapid onset of epidural anesthesia is necessary, such as the emergent caesarean delivery.
- It has a fast onset of action despite having a very high pKa (having a low percentage of molecules in nonionized form) because it can be safely administered in very high concentrations.
- Chloroprocaine spinals are not standard practice, but there is interest in the academic community in trying to resurrect the chloroprocaine spinal for ambulatory

procedures.

- The splash block involves application of chloroprocaine directly into a surgical wound. It is a technique that has been taught and performed by a number of the authors and editors of this book in emergency obstetrical cases and other situations involving the need for dense topical anesthesia. Watch the upcoming literature for the results of ongoing investigations on the pharmacokinetics and safety of this technique.

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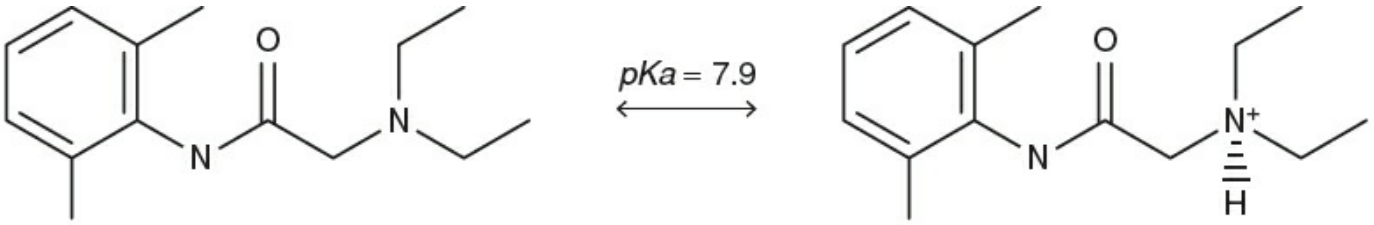
# Use Bicarbonate as a Buffer to Local Anesthetics—Especially for Skin Infiltration

Vladyslav Melnyk, MD, Hooman Rastegar Fassaei, MD, and Steven L. Orebaugh, MD

Local anesthetics reversibly block impulse conduction along nerve axons and other excitable membranes via direct inhibition of the sodium current. The local anesthetics used clinically consist of a lipid-soluble substituted benzene ring linked to an amine group via an amide or an ester linkage and they act as weak bases ($pK_a$ range is 7.6 to 9). These agents are poorly soluble in water and therefore are usually stored and distributed in acidic hydrochloride salt solutions (pH 3 to 6). In this form, the local anesthetics predominantly exist in a more water soluble cationic form. The protonation process is readily reversible, and the relative proportions of neutral base and conjugate acid will equilibrate according to the Henderson–Hasselbalch equation:

$$Log\frac{[protonated]}{unprotonated} = pK_a - pH$$

The proportions of the drug that exist in each form depend on the pH of the solution and the pKa, or dissociation constant, of the particular drug. This dissociation constant (pKa) denotes the pH at which the ionized and neutral forms of the molecule are present in equal concentrations. Since the pKa of most local anesthetics is in the range of 7.6 to 9.0, the larger fraction in the body fluids at physiologic pH will be the charged, cationic form.




**Unprotonated (Conjugate base)**

Favored at pH >7.9
More lipophilic
Rapid diffusion through lipid membranes

**Protonated (Conjugate acid)**

Favored at pH <7.9
More soluble in aqueous solution
Increased affinity for sodium channels

**While major aspects of pharmacokinetic and pharmacodynamic behavior of local anesthetics have been elucidated, our understanding of their action is not fully complete. It appears that both protonated and unprotonated forms of local anesthetics play separate important roles**. Following local injection into tissues, the spread of the drug through lipid-rich cell membranes is facilitated in their neutral form. Since the ultimate target of local anesthetics is the intracellular portion of the sodium channels, deprotonation enhances lipophilicity and thus intracellular entry of the drug, potentially resulting in faster onset and increased potency. Finally, once inside the cell protonation facilitates binding of local anesthetics by increasing their affinity for target sodium channel sites in their open or inactivated states.

This picture may be oversimplified, and the sequence of events following local injection likely involves repeated protonation and deprotonation during diffusion and interaction with membrane and sodium channels. Significant evidence points to the fact that local pH has important effect on these events.

## Buffering Local Anesthetics to Decrease Onset Time

Stock solutions will contain significantly larger proportion of local anesthetics in their protonated form as described above since pH is typically significantly lower than pKa. Increasing the pH of the carrier solution of local anesthetics with sodium bicarbonate will favor the formation of a neutral base form of the drug facilitating diffusion through axonal membrane.

The addition of sodium bicarbonate to local anesthetic solutions has been reported to decrease the time of onset of conduction blockade. Alkalinization of solutions of bupivacaine or lidocaine accelerates the onset of brachial plexus and epidural blockade in some studies but not others. In addition, there are data that suggest that alkalinization of lidocaine decreases the duration of peripheral nerve blocks if the solution does not also contain epinephrine, but results between different trials are also incongruent.

## Buffering Local Anesthetics to Decrease Pain on

## Injection

Local anesthetics cause pain on injection, what has been frequently attributed to significant acidity of their commercial preparations. While physiologic pH ranges between 7.35 and 7.45, stock lidocaine solutions can reach pH of 3.5. Adding bicarbonate to increase pH of the solution may thus result in significant improvement in discomfort on injection.

A significant number of studies have been conducted and published that compare local injection of stock lidocaine with its alkalinized preparations. Unfortunately, while many trials report significant improvement in pain on injection, the results are not uniform.

**Meta-analysis of 23 parallel-group and crossover randomized controlled trials by Cochrane collaboration revealed statistically significant reduction in pain scores as well as increased patient preference for buffered lidocaine**. It also demonstrated a greater decrease in pain intensity when alkalinized solutions containing premixed epinephrine were used, stock preparations of which typically have lower pH.

Nevertheless, authors note significant heterogeneity in reported results between different studies. Moreover, the mean reduction in pain was merely between −0.95 units in parallel-group and −1.98 units in crossover studies on a 10-point pain intensity scale, which raises the question of clinical significance of these results (95% confidence intervals were −1.42 to −0.49 and −2.62 to −1.34, respectively).

The main downsides of many published trials are difficulties with allocation concealment, and the use of one injection per patient or sequential injections in crossover-type study designs, which may significantly affect observed results. Better study designs, such as using simultaneous injection may address some of these issues, but they are more difficult to implement.

Despite the transient nature of pain on injection, patients who require multiple injections in one setting or return for repeat procedures requiring local anesthetics are likely to benefit significantly from alkalinization. This practice can improve patient comfort and potentially obviate the need for sedatives and anxiolytics, as well as help avoid general anesthesia for minor procedures.

Still, while the high concentration of hydrogen ions in unbuffered solution is frequently cited as the most likely culprit, the cause of pain on skin infiltration is probably more complex and depends on factors other than pH alone. For example, procaine (pH 4.3) is more acidic but less painful than lidocaine (pH 6.3). Alternatively, the pain-reducing effect of sodium bicarbonate may represent a shift of the equilibrium between the ionized and nonionized forms of lidocaine, favoring formation of the nonionized form. The more rapid diffusion of the nonionized form may result in faster inhibition of pain transmission, thereby preventing nociceptive impulses from being

fully appreciated.

## Stability of Buffered Lidocaine

There is a concern that buffering of local anesthetic solutions decreases their shelf life due to increased sensitivity to photodegradation and greater tendency to precipitation. Available evidence largely disputes these points. Conservative estimates based on analysis of buffered lidocaine stored in plastic syringes, under refrigeration suggest that chemical stability will be maintained for up to 1 month. However, there are also data supporting stability of up to 3 months when stored in glass vials, even at room temperature, and with exposure to light. No precipitation or discoloration was noted in either set of experiments. pH remains stable or mildly increases during storage.

Notably, however, epinephrine in premixed solutions degrades much more rapidly. Recommended shelf life for epinephrine-containing solutions is only 1 week following buffering.

## How to Prepare Buffered Lidocaine for Skin Infiltration

Add 1 mL of 8.4% sodium bicarbonate at a concentration of 1 mEq/mL to 9 mL plain 1 or 2% lidocaine HCl.

### TAKE HOME POINTS

- Local anesthetics are weak bases with limited solubility in water. They are marketed in acidic salt solutions to improve stability and shelf life.
- Buffering with bicarbonate solution increases the neutral (nonionized) fraction, which can rapidly cross the lipid-rich neural cell membrane and then be converted to the ionized form to act on the sodium channel.
- Some (but not all) studies have shown that buffering local anesthetic decreases the onset time for brachial plexus and epidural blocks.
- Buffering of stock lidocaine solution leads to significant (although modest) reduction in pain on injection and is generally preferred by the patients. There is little to no reason not to buffer your local anesthetic for skin infiltration. Remember that, if at all possible, you want to avoid saying, “A little stick and a burn, Mr. Doe, a little stick and a burn.”

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# The Hows, Whys, Ins, and Outs of Succinylcholine or Succinylcholine—Still a Useful Anesthesia Adjunct

Christopher R. Lee, MD and Edwin G. Avery IV, MD

An 18 year-old fun-loving young man arrives at the trauma bay after suffering from third-degree burns over 50% of his body. Apparently, there was a mixing of fireworks and gasoline to "enhance their potency" which did not end well. Some of the burns involve the face/neck and although the vital signs are acceptable his voice sounds odd and he is complaining of difficulty in breathing. The decision is made to secure his airway immediately and you are handed a syringe of succinylcholine. Is this going to be safe under the present conditions? What would be the contraindication for succinylcholine in this patient and why?

## Introduction

As an anesthesiologist, one might like to think of oneself to be kind of like…Batman. Not necessarily because of a god-like physique, a tragic backstory, or a cave hangout, but because we have a seemingly endless assortment of gadgets and gizmos for (almost) every situation. All we really need now is a handy utility belt to keep everything organized. Let us just pause for a moment and imagine it. A holster for your laryngoscope loaded with a trusty Mac blade (sorry to the Miller-blade users), a pouch for extra EKG patches, and an assortment of preloaded syringes neatly organized and easily accessible. Now, in keeping with the anesthesiology-batman-utility-belt motif, we would have to say that of all the drugs in our belt, the neuromuscular blocking drugs would be right up there with the Batarang or the Bat-rope in importance.

## Neuromuscular Blockers Broken Down

Neuromuscular blockers (NMB) are broadly divided into two groups based on their overall mechanism. In one corner you have the nondepolarizing NMBs (any drug with -

curium or -curonium in the name) and in the other corner you have the depolarizing NMBs of which there is only one in clinical use—succinylcholine (aka sux).

Yes, good ol' sux. The favorite of board examiners everywhere. And rightly so, since succinylcholine is a great drug that is mostly safe and can be a life-saver in sticky situations (like the Batarang). But, it also has a number of quirks that need to be mastered by the anesthesiologist. We will hit on the most important ones in this chapter but first we need to delve into exactly why succinylcholine does what it does.

## The Neuromuscular Junction and Skeletal Muscle Contraction

In order to understand how succinylcholine works, we need to discuss the physiology surrounding the neuromuscular junction (NMJ) and muscle contraction itself. If you recall, the NMJ is the communication point between the nervous system and the muscle fiber itself. It consists of the terminal bouton (or button if you are from the good ol' USA) and a specialized portion of muscle fiber membrane called the motor endplate. Inside the terminal bouton are vesicles containing acetylcholine and across the 20 nm gap on the motor endplate sit millions of nicotinic acetylcholine receptors. These receptors are actually a ligand-gated ion channel consisting of five protein subunits named alpha (there are two of these), beta, delta, and epsilon. But actually only the alpha subunits matter because they are the ones that actually bind the acetylcholine molecule. Now let us talk about the actual process, and then we can see how succinylcholine fits in. **Step 1:** A motor nerve is stimulated, and an electrical signal is transmitted down the axon (thanks to voltage-gated sodium channels) to the terminal bouton. **Step 2:** Voltage-gated calcium channels open (in response to the aforementioned electrical signal) letting in a rush of calcium ions. **Step 3:** Calcium ions interact with those acetylcholine-containing vesicles and cause them to fuse with the plasma membrane. **Step 4:** Acetylcholine molecules are dumped into the synaptic cleft and diffuse across the gap to the motor endplate. **Step 5:** One acetylcholine molecule binds to each of the alpha subunits in the acetylcholine receptors (remember that there are two alpha subunits). This binding causes conformational change in the receptor which opens the ion channel allowing sodium and calcium to flow into the cell (and potassium to leak out) thereby resulting in a local membrane depolarization. **Step 6:** Acetylcholine is rapidly metabolized by acetylcholinesterase. **Step 7:** Once enough receptors are activated, the endplate depolarizes enough to activate the nearby voltage-gated sodium channels. **Step 8:** A chain reaction ensues: voltage-gated sodium channels open, sodium rushes in depolarizing the membrane further, which opens even more voltage-gated sodium channels, and on and on. **Step 9:** The wave of membrane depolarization progresses down into T-tubules triggering calcium release from the

sarcoplasmic reticulum. **Step 10:** Intracellular calcium interacts with troponin facilitating the crossbridge formation between actin and myosin and, ultimately, muscle contraction. Just a few steps short of a 12-step program but now we are all on the same page as to how things work.

So where do NMBs come into this picture? Both depolarizing and nondepolarizing NMBs act at the acetylcholine receptor. **Nondepolarizers act as competitive antagonists** and block acetylcholine from binding to the receptor, in turn, preventing the ion channel from opening. **Succinylcholine, on the other hand, acts as a competitive agonist.** In other words, it activates the receptor, opens the ion channel, and causes a disorganized depolarization.

## Succinylcholine—Mechanism of Action

Succinylcholine's primary mechanism of action (Phase I block) is due to its structure which is essentially two acetylcholine molecules linked end to end by acetate methyl groups. It binds to the acetylcholine receptor resulting in sodium and calcium influx, but because it is not broken down by acetylcholinesterase, sux clings to the receptor resulting in prolonged depolarization. In other words, the membrane becomes depolarized resulting in contraction, but the succinylcholine does not disengage from the receptor fast enough, thus preventing further activation or contraction. Eventually succinylcholine does dissociate from the receptor and diffuses away from the NMJ where it is finally broken down by butyrylcholinesterase (aka: plasma cholinesterase, aka: pseudocholinesterase depending on which textbook you read). We should note that sux's termination of action is due to its diffusion away from the NMJ, and NOT due to the (very efficient) activity of butyrylcholinesterase.

But that is not all. In the setting of high-dose succinylcholine (either by way of a single large dose, repeat doses or, even an infusion) a Phase II block occurs. A Phase II block is one of those phenomena that nobody understands too well, but examiners love to ask questions about it anyway. (It might be funny, if one really was not quite ready to take their oral Anesthesiology Boards, to show up dressed like Batman to try to get thrown out). Essentially, a Phase II block is when the membrane repolarizes but (for some unclear reason) it fails to respond to acetylcholine and results not only in a prolonged motor block but also displays a fade with both a train of four and tetany (similar to what is seen with a nondepolarizing block). A Phase II block IS antagonized by acetylcholinesterase inhibitors like neostigmine; however, there is some debate about whether one should reverse a Phase II block with neostigmine or just let it wear off. We were taught that it is safest for the patient to let it wear off, which is what we believe most of our colleagues would do.

Now that we are on the topic of prolonged duration of action, this is as good a place

as any to talk about **butyrylcholinesterase deficiency**. Deficiency of this enzyme can be either due to decreased production, particularly in the setting of liver disease, old age, or pregnancy; or due to a point mutation in one or both alleles. A deficiency is typically discovered only after a patient receives succinylcholine (or mivacurium, or ester local anesthetics). However, it can be tested for by administering dibucaine intravenously. Dibucaine inhibits normal butyrylcholinesterase and allows for the calculation of the **dibucaine number**. An individual with two normal alleles will have a high dibucaine number (70 to 80) and a normal response to succinylcholine. A heterozygous individual will have a dibucaine number of 50 to 60 and their response to sux will be prolonged 50% to 100% (20 to 30 minutes). An individual who is homozygous for the mutation will have a dibucaine number of 20 to 30 and the duration of succinylcholine will be 4 to 8 hours (the PACU is going to love you when you bring one these out of the operating room…).

## Indications for Succinylcholine

The primary benefits behind succinylcholine lie in its incredibly rapid onset (30 to 60 seconds), the dense paralysis that it creates, and its short duration of action (less than 10 minutes). This makes the drug remarkably well suited for a number of situations. The clearest indication for succinylcholine is the airway indication, that is, the rapid sequence intubation in situations where there is a high risk of regurgitation and/or aspiration on induction. It is also ideal for short cases where endotracheal intubation is indicated and a very rapid but very dense neuromuscular blockade is needed, or in cases where prolonged neuromuscular blockade is contraindicated (to facilitate evoked potential monitoring for example). Succinylcholine can also literally be a life-saver in the setting of severe laryngospasm or need for emergent reintubation in the operating room. However, remember, if you have reversed a patient's nondepolarizing NMB with neostigmine and then have to give succinylcholine to deal with a postextubation emergent airway issue, remember that in such a situation succinylcholine is **not** short-acting.

It is relevant that before the availability of sugammadex to reverse the action of nondepolarizing neuromuscular blockade, the use of succinylcholine infusions was an option employed by some anesthesiologists to get good paralysis which can abate rapidly. It is important to know that the use of a sux drip in this manner can precipitate a Phase II blockade in as many as 33% of individuals. In this situation, it is probably best to avoid the administration of neostigmine even though it will antagonize the Phase II block as it complicates the neuromuscular physiology and opens up the possibility of rebound muscular blockade. So, the best course of action if your patient has a Phase II block is to let it wear off and this is accomplished with Train-of-Four monitoring with

the goal of observing four strong twitches. It is likely that with the availability of sugammadex we will not be seeing too many sux infusions anymore (although I am sure the use of a sux drip would be cheaper than administering sugammadex to a patient as long as the patient on a sux drip does not develop Phase II blockade), but it is worth asking your more "established" colleagues about it.

Yet another bonus of sux is that it can be administered by the intramuscular route when in a pinch. For example, at our institution, every once in a great while, we take a patient into the operating room when we cannot find a vein and they refuse intraosseous access or a central line. We put the standard monitors on and then give them some sevoflurane to coax out a vein and it works fine in the great majority of the time we use this rare technique. However, if the patients develop bronchospasm or laryngospasm in this situation, intramuscular sux at 4 mg/kg can get you dense paralysis in about 2.5 minutes, and might also get you a Phase II blockade to deal with which we think is a small problem to contend with a serious situation like bronchospasm and/or laryngospasm with no intravenous access. Even if this is not a practice that occurs with you personally or at your hospital, you still need to know about intramuscular succinylcholine. This is because it is also your choice in the dreaded emergence or extubation flail if the patient's IV gets pulled out and you have to reintubate. You should have it immediately available for each case where you administer neuromuscular blockade or instrument an airway, since laryngospasm if terrifying and can be really dangerous for the patient. A wise anesthesiologist once said, "You might need to give succinylcholine emergently once in every 200 cases but when you need it, you need that and only that, and you need it fast."

While another wise anesthesiologist once said "It is tough to kill somebody with succinylcholine who was appropriately preoxygenated," it can happen if you have not taken our chapter to heart, but what is much more common with the use of sux (i.e., average of about 50% of patients) is the pesky myalgias, and they can be very troublesome and persistent (i.e., up to a week) in our patients. Even if the sux saves their life or helps keep them out of harm's way, we still think it is worth enduring the myalgia blowback. That said, the high frequency of myalgias is probably, in our opinion, the best reason not to electively use sux as a first-line NMB in routine cases, especially when we now have sugammadex available to us. However, there is sure to be some variation on the use of routine, first-line use of succinylcholine, so if you are just starting out, look around and ask round. Lastly, do not forget its benefit in electroshock therapy preventing whole body seizure and potential injury to the patient.

## Cardiovascular Effects of Succinylcholine

Succinylcholine acts not only on the nicotinic acetylcholine receptors on the NMJ, but

also on the muscarinic receptors in the autonomic nervous system. In adults (including Batman, but not Superman), this can result in increased catecholamine release and subsequent tachycardia; however, this is typically blunted by the hemodynamic effects of other induction agents like propofol. In infants and small children (remember that children are NOT little adults), succinylcholine use with their immature sympathetic systems can cause bradycardia (this is one of the many reasons why sux should be avoided in children except in emergencies).

## Musculoskeletal Effects of Succinylcholine

The disorganized discharge that occurs when succinylcholine binds to the acetylcholine receptor is manifested clinically as muscular fasciculations. These fasciculations can actually be prevented by "pretreatment" with a small dose of a nondepolarizing neuromuscular blocker like rocuronium; however, in this situation one should increase the administered dose of sux to 1.5 mg/kg to ensure full effect. Patients who have received sux have also complained of myalgias postoperatively. It was thought that this was due to the fasciculations, but it appears that this is not the case as pretreatment with rocuronium does not prevent myalgias. Succinylcholine has also been shown to cause an increase in both intracranial and intraocular pressure, which can present a contraindication in certain neurologic cases (where herniation is a risk) and in ocular surgery (especially when dealing with a ruptured globe). Intragastric pressure is also elevated upon sux administration. One would think that this would throw a wrench in the use of sux in rapid sequence intubations, but it turns out that not only does pretreatment with a nondepolarizing neuromuscular blocker prevent the bump in intragastric pressure, but succinylcholine itself also increases the lower esophageal sphincter tone. The bottom line here is that the use of succinylcholine does not increase risk of regurgitation on induction.

## Hyperkalemia and Succinylcholine

Hyperkalemia is, without a doubt, the best-known complication associated with succinylcholine. The rise in potassium (usually between 0.5 and 1 meq/L) is due to the succinylcholine's action on the acetylcholine receptor. Remember that on binding, sodium and calcium flow into the muscle fiber while potassium leaks out. In healthy patients, this is not a big deal. Some anesthesiologists will avoid using succinylcholine in patients with chronic or end-stage renal disease. However, as long as the preoperative potassium is within reasonable limits, using succinylcholine is acceptable because renal insufficiency does not cause the serum potassium to increase more than in otherwise healthy patients.

Severe and even life-threatening hyperkalemia can occur in patients who have

suffered denervation injuries. In the setting of denervation we see a proliferation of extrajunctional acetylcholine receptors. Now, I am not totally sure if this is physiologically accurate, but I imagine a muscle fiber sitting there wondering where all the acetylcholine went and throwing out extra receptors just in case. The result is that these extrajunctional receptors not only increase the sensitivity to succinylcholine but also dramatically increase the amount of potassium that is dumped into the circulation.

Specific instances where we see extrajunctional proliferation include severe third-degree burns; several neurologic diseases including spinal cord injury and paralysis, severe stroke, multiple sclerosis, muscular dystrophy, Guillain–Barre syndrome, tetanus, and severe Parkinson's disease; severe critical illness (prolonged infection and prolonged bed rest); and even massive trauma (closed head injury or hemorrhagic shock). Interestingly enough, succinylcholine is NOT contraindicated in patients with cerebral palsy (though there is an increase in extrajunctional ACh receptors, the degree of potassium release is no different from healthy patients).

The time course of extrajunctional ACh Receptor proliferation is minimal during the first 48 hours, but peaks after 7 to 10 days. What this means for you is that sux is not contraindicated in the trauma bay (or for the first 48 hours) when you have to intubate the patient covered in third-degree burns (assuming that paralysis is indicated of course).

## Muscular Dystrophies and Succinylcholine

While we are talking about the relationship between neurologic disorders and the use of sux, we should spend a few lines on muscular dystrophies (MDs). Duchenne muscular dystrophy (DMD) is the most common type. It results from a missing dystrophin gene which is found on the X chromosome and typically affects males as early as 4 years of age. Becker muscular dystrophy (BMD) is a less severe variant caused by a mutation (again on the X chromosome) resulting in a truncated and partially functional dystrophin gene. The result is progressive muscular wasting which leads to poor balance, difficulty or inability to walk, respiratory distress, and cardiomyopathy.

The use of succinylcholine in patients with MD results in severe and life-threatening hyperkalemia (i.e., cardiac arrhythmias) for a couple of reasons. First one is the upregulation of extrajunctional ACh receptors already discussed, but additionally succinylcholine causes severe rhabdomyolysis in this population. This is further complicated because symptoms for MD do not show up until the age of 4 (in the case of DMD) or 7 to 8 years (in the case of BMD). Because of this delay, routine use of succinylcholine should be avoided in pediatric populations. Allow me to make one last point regarding muscular dystrophy and its association with Malignant Hyperthermia —there isn't one.

## Malignant Hyperthermia and Succinylcholine

With that segue, let us talk about good ol' malignant hyperthermia (MH)—A board favorite that most of you will (hopefully) never see in clinical practice. You may recall that MH is due to a mutation of the ryanodine receptor gene. This mutation is typically asymptomatic until the patient is exposed to a triggering agent such as a volatile anesthetic (halothane, sevoflurane, desflurane, etc.) and, you guessed it, succinylcholine. I will not go into a whole lot of detail about MH, but remember the key point is that the aforementioned triggering agent results in a massive release of calcium in the myocyte resulting in muscle contraction. The prolonged contraction uses up ATP stores resulting in a hypermetabolic state, which, in turn leads to lactic acidosis, increased oxygen consumption, heat production, and a severe hypercarbia and corresponding respiratory acidosis. The clinical outcome of all this is severe hyperthermia, tachypnea, tachycardia, respiratory distress, muscle rigidity (especially spasm of the masseter muscle), and rhabdomyolysis. At this point it would be worthwhile to point out that while masseter spasm IS an early symptom of MH, it is NOT pathognomonic for MH. To make things even more confusing, masseter spasm has been shown to occur as a result of succinylcholine administration, more commonly in pediatric patients (another reason to avoid routine use of sux in this population).

MH is typically inherited in autosomal dominant fashion and it has been associated with hyperkalemic and hypokalemic periodic paralysis as well as central core disease and King Denborough Syndrome (two extremely rare muscle syndromes that you will probably only see on a board question). Because of this, a thorough personal and family history (specifically asking about complications with prior anesthetics) is essential prior to using succinylcholine.

## Myopathies and Succinylcholine

Yet another favorite source of questions by board examiners everywhere (Could Board Examiners beat Batman in a fistfight? Definitely not…a round of golf maybe…but not a fistfight) lies in the relationships between myasthenia gravis (MG) and Lambert–Eaton Myasthenia Syndrome (LEMS) and neuromuscular blocking drugs (especially succinylcholine).

MG is an autoimmune disorder featuring antibodies that block/destroy the nicotinic acetylcholine receptors in the NMJ. Patients with MG typically display oculomotor weakness, facial weakness, and bulbar palsy which worsens over the course of the day, and responds well to acetylcholinesterase inhibitors like neostigmine and pyridostigmine. Because patients with MG have fewer functional ACh receptors, they are less sensitive to succinylcholine (and more sensitive to nondepolarizers).

LEMS is an autoimmune disorder that attacks the presynaptic voltage-gated calcium

channels in the NMJ (glad we covered all of this earlier in the chapter right?) which prevents acetylcholine release. These patients typically display proximal muscle weakness which IMPROVES over the course of the day. It is also frequently associated with small cell carcinoma of the lung. Individuals with LEMS display increased sensitivity to BOTH succinylcholine AND nondepolarizers.

***Author Bragging Moment:** I actually diagnosed a family member with this disease as a first year medical student. He couldn't do anything during the day because of weakness and fatigue, but he would go out dancing at night. Everyone thought he was lazy and faking sick. But after several rounds of plasmapheresis and IVIG he showed significant improvement and he was able to get up off his parents' couch, turn off the Batman movies, and go to work. He did not have cancer. (Faking cancer would also be a good coverup story for the real Batman but we do like the millionaire playboy thing better).

## TAKE HOME POINTS

- Succinylcholine is a useful and mostly safe depolarizing neuromuscular blocker.
- If Batman had a DEA license he would definitely put sux in his utility belt.
- Phase I block following sux use has to just wear off on its own and will usually occur in less than 10 minutes (unless the patient has a pseudocholinesterase deficiency).
- Phase II block following sux can be treated with neostigmine but it is also OK and likely safer to just let it wear off as giving the neostigmine creates the risk of rebound muscular weakness. We recommend letting it wear off. It is the most reliable way to get out of this clinical situation and ultimately safest for the patient.
- Homozygous pseudocholinesterase deficient individuals may take anywhere from 4 to 8 hours to recover normal neuromuscular function.
- Succinylcholine is primarily indicated in adults to facilitate rapidly securing the airway and while it can be used in children its use should be reserved for emergencies only as there are a number of reasons its use may be unsafe in children. If used in children, pretreatment is required to avoid bradycardia.
- Succinylcholine use is associated with a transient increase in serum potassium that can be life threatening in select situations (prolonged bed rest, diffuse third-degree burns if used after the first 24 to 48 hours, existing muscular dystrophy, tetanus, hyperkalemia, renal insufficiency, denervation injuries, spinal cord injury, paralysis and a number of neurologic diseases (multiple sclerosis, Guillain–Barre, severe Parkinson's disease).
- Succinylcholine can be administered intramuscularly at a dose of 4 mg/kg with fairly rapid effect (i.e., 2.5 minutes) but be mindful that Phase II block may occur.

- Routine use of succinylcholine in all elective cases is not a great idea related to the high observed frequency and persistence of myalgias given that sugammadex is now available.
- Use of succinylcholine in patients with muscular dystrophies should be **strictly** avoided as it may result in life-threatening hyperkalemia.
- Succinylcholine is a known triggering agent for MH.
- Masseter muscle spasm is an early sign of MH but NOT pathognomonic for MH.
- Individuals with myasthenia gravis are less sensitive to succinylcholine and more sensitive to nondepolarizing neuromuscular blockers.
- Individuals with Lambert–Eaton Myasthenia Syndrome display increased sensitivity to both succinylcholine and nondepolarizing neuromuscular blockers.
- Succinylcholine is a perennial favorite for those people who devise the exams that anesthesiologists must take. Even if succinylcholine is not a big part of your day-to-day practice, before every exam take time to commit the physiologic and pharmacologic facts about succinylcholine to firm memory. Like Crash Davis said in the movie, "You're going to have to study them, you're going to have to know them. They are your friends." Because there isn't any reason at all to miss even one succinylcholine question.
- But it is not just the board exams that are important – succinylcholine first came into clinical use in the 1950s and through the decades has been used by hundreds of thousands or even millions of anesthesia providers. If you are ever trying to justify your clinical judgment and decisions to any "inquiring" party, you had better know why you gave or why you didn't. Lack of knowledge, awareness, or experience won't do to justify your answer when it comes to succinylcholine.

## Suggested Readings

Donati F, Bevan DR. Neuromuscular blocking agents: Chapter 16. In: Barash PG, Cullen BF, Stoelting RK, eds. Clinical Anesthesia. 5th ed. Lippincott Williams and Williams. 2005:421.

Neuromuscular Blockers and Reversal Drugs: Chapter 19. Pharmacology and Physiology for Anesthesia. In: Hemmings HC Jr, Egan TD, eds. Saunders; 2013:325.

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# Don’t Get Burned by Incomplete Reversal of Neuromuscular Blockade

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An 80-year-old female who is obese and has COPD undergoes an emergency exploratory laparotomy under general anesthesia by endotracheal tube. At the end of surgery, how will you decide how to reverse her neuromuscular blockade? How will you know when she is ready for extubation?

## Introduction

Neuromuscular blockade (NMB) plays a key role in general anesthesia by facilitating intubation and ventilation during surgery, by relaxing muscles at the surgical site, and by preventing involuntary patient movements during surgery. Thus, NMB can help improve surgical conditions and reduce the risk of surgical complications. However, this comes at a cost—the risk of inadequate reversal of NMB at the end of surgery.

Neuromuscular blocking agents (NMBAs) are classified as depolarizing or nondepolarizing, depending on their mechanism of action. This chapter will specifically deal only with issues relating to nondepolarizers.

## How Do Nondepolarizing Muscle Relaxants Work?

First, a brief description of normal neuromuscular transmission: When a nerve impulse reaches the end of a nerve terminal, vesicles containing acetylcholine (ACh) are released into the neuromuscular junction (NMJ). Some of these ACh molecules will bind to ACh receptors at the distal portion of the NMJ and activate muscle contraction. In the meantime, acetylcholinesterase is working to break down ACh.

Non-depolarizing NMBAs act as competitive antagonists at the postsynaptic ACh receptor. They bind to the same receptor subunits as ACh, but do not induce a conformational change that leads to muscle activation. In addition, nondepolarizing NMBAs also inhibit presynaptic ACh receptors at the nerve terminals and thereby impair the recruitment of ACh. Nondepolarizing NMBAs can be classified, according to

their basic chemical structure, into aminosteroids (e.g., rocuronium, vecuronium, pancuronium) or benzylisoquinoline (e.g., atracurium, cisatracurium, mivacurium) compounds.

## How Do We Monitor Neuromuscular Blockade During Surgery?

During general anesthesia, the rationale for neuromuscular monitoring is four-fold: (1) to establish depth of paralysis for intubation and during the surgical procedure, (2) to determine readiness for reversal at the end of surgery, (3) to determine the dosage of reversal agent to be used, and (4) to gauge recovery of respiratory muscle function after reversal. During surgery, there are both quantitative and qualitative ways to monitor the extent of blockade. (During emergence from anesthesia, there are also clinical assessments that are commonly used. More on that later!)

To monitor the extent of blockade, the most common measure used is the train-of-four (TOF) ratio. We deliver four supramaximal stimuli (at intervals of 0.5 second) with a peripheral nerve stimulator, and measure or observe the response. This test is based on the concept that ACh is depleted by successive stimulations. Quantitative devices analyze evoked muscle contractions or the muscle action potentials that result. Qualitative assessment is our best guess assessment of what we observe. First, we observe the number of twitches after the four stimuli. (We call this a twitch count.) If four twitches are present, the fourth twitch response is compared with the first twitch response, and a ratio of 0 to 1 is calculated. This is known as the TOF ratio.

A rough way to interpret this info is as follows: A **deep blockade** will have 0 twitches after TOF stimulation. A **moderate block** will have one to three twitches present. A light block will have four twitches, and there will be an obvious fade in intensity in comparison to the first twitch (equates to TOF ratio of 0.1 to 0.4). A minimal block will have minimal or no fade in intensity of the fourth twitch (equates to TOF ratio 0.4 to 0.9).

The reader should be aware that there are other modalities of stimulation in use—such as double burst suppression or looking for fade during tetanic stimulation. However, the TOF ratio is most commonly used in dosing guidelines for reversal agents.

## How Do We Reverse Neuromuscular Blockade?

As previously stated, nondepolarizing muscle relaxants work by competing with ACh at the NMJ, thus blocking neuromuscular transmission. Muscle function recovery occurs by the gradual diffusion, metabolism, and redistribution of these agents. This recovery of NMJ takes time. So, how can we help accelerate the recovery of neuromuscular

transmission? In general, there are two ways to do this. The traditional approach has been to administer a drug that increases the concentration of ACh at the NMJ, thus decreasing the relative concentration of NMBAs at the site. The relatively new approach to this problem is to use a drug that actually removes NMBAs from the circulation.

How do we increase the concentration of ACh at the NMJ? We can accomplish this by reversibly inhibiting the enzyme (cholinesterase) that is responsible for breaking down ACh. These drugs are thus called cholinesterase inhibitors. The drug most frequently used for this purpose is neostigmine, but edrophonium is another example.

How do we remove NMBAs from the circulation? At present, we have one drug that accomplishes this—sugammadex. Sugammadex encapsulates steroidal type NMBAs in the plasma. It works best with rocuronium, but also works with vecuronium. It creates an intense diffusion gradient, so that NMBA molecules diffuse away from the NMJ back into the plasma, where further encapsulation occurs. The encapsulated molecule gets secreted by the kidneys. By removing the NMBA from the NMJ, this reversal agent facilitates normal neuromuscular transmission between nerve and muscle.

## How Do We Define Adequate Recovery From Neuromuscular Blockade?

In general, residual NMB has been defined using quantitative neuromuscular monitors. However, in every day practice, most of us are using qualitative neuromuscular assessment—a visual estimate of the TOF response. Until the early 1990s, a TOF ratio of less than 0.7 was considered inadequate muscular recovery, based on studies that showed that patients who are given NMBAs had impaired pulmonary function at TOF ratios less than this. In the mid-1990s, this important threshold was reassessed, and new evidence from awake patients and clinical studies supported using a ratio of 0.9 as a more accurate and safer indicator of adequate reversal. Alright, so now we know our goal to ensure safe extubation—a TOF ratio greater than 0.9.

## What Is the Incidence of Inadequate Reversal?

Multiple investigators have examined the incidence of inadequate reversal, as defined as the incidence of TOF less than 0.9 on arrival to PACU. Studies have shown inadequate reversal in 30% to 60% of patients! One large meta-analysis calculated the rates of inadequate reversal to be 41% for intermediate duration muscle relaxants and 72% for long-acting muscle relaxants (pancuronium). This data all dates to the era when cholinesterase inhibitors were the only option available for reversal.

## What Are the Clinical Implications of Incomplete

## Reversal?

Not every patient who has residual blockade suffers from clinical consequences. The healthy patient has large physiologic reserve, and is able to compensate. However, those patients at extremes of age, or who have COPD, are morbidly obese, or have obstructive sleep apnea will have higher risks of complications. Adverse events tend to be respiratory related.

Respiratory issues include airway obstruction and inadequate oxygenation and ventilation. Impaired coordination of pharyngeal muscles and reduced upper esophageal sphincter tone impair the ability to swallow and increase the risk of aspiration. A study of almost 700 patients undergoing a mix of abdominal, gynecologic, and orthopedic surgical procedures found that patients who had residual block in the PACU had a 3½-times higher risk of postop pulmonary complications.

Patients who are awake and incompletely reversed will experience unpleasant symptoms of muscle weakness. However, many patients will still be sedated from residual anesthetics or opioids, and may not be aware that they are weak.

Another consequence of incomplete reversal is prolonged PACU stay. For example, one study found that patients who had TOF ratios less than 0.9 spent an average of 80 minutes longer in the recovery room.

## Which Groups Have Higher Risk of Incomplete Reversal?

There are limited data regarding which groups have higher risk of incomplete reversal. There are some data to suggest that the elderly, obese, and those with liver or kidney dysfunction may have higher risk for incomplete reversal.

There are a few medical conditions in which the patients are more sensitive to nondepolarizing drugs. Patients with myasthenia gravis have antibodies against ACh receptors in the NMJ. This leads to decrease in functional ACh receptors and sensitivity to nondepolarizing muscle relaxants. Lambert–Eaton myasthenic syndrome is a paraneoplastic autoimmune disease associated with small cell carcinomas. Antibodies directed against calcium channels result in decreased release of ACh at the NMJ. These patients are also sensitive to nondepolarizing muscle relaxants.

Some other things to be aware of: There are some medications which enhance NMB. Volatile anesthetics, aminoglycoside antibiotics, dantrolene, magnesium, lidocaine, and lithium are examples of drugs that can enhance blockade. In addition, there are some physiologic conditions that can slow NMBA metabolism or cause problems with reversal—for example hypothermia, acidosis, hypokalemia.

Another type of drug interaction to consider occurs as a result of switching among different NMBAs during a case. The duration of action may become less predictable,

and can be prolonged. For example, the duration of the block by vecuronium is longer than expected if pancuronium has been administered initially. This most likely occurs because a larger dose of the longer-acting drug is administered first. So when smaller doses of vecuronium are given to maintain the block, the majority of receptors are still occupied by pancuronium. A second issue occurs when mivacurium is part of the mix (mivacurium is no longer available in the United States, but is still used worldwide). If pancuronium, vecuronium, or atracurium are administered prior to mivacurium, the duration of the mivacurium block can be significantly prolonged. It appears that since mivacurium is metabolized by plasma cholinesterase, and these NMDAs inhibit cholinesterase, the elimination of mivacurium from plasma is prolonged. A third interaction occurs when NMDAs of different classes are combined. Synergy is seen when you combine an aminosteroid and benzylisoquinoline (e.g., metocurine and pancuronium, (+)-tubocurarine and pancuronium and cisatracurium and vecuronium or rocuronium). This is believed to happen because the different class structures bind to different subunits of the ACh receptor.

## More About Neuromuscular Monitoring

The most accurate determination of TOF ratio is with a device that makes a quantitative assessment. These are properly called neuromuscular monitors. Several methods have been used, including acceleromyography, kinemyography, or electromyography. The use of such devices has been shown to reduce residual NMB, signs of muscle weakness, and adverse respiratory events after tracheal extubation. Unfortunately, there are multiple barriers to clinical use, such as ease of use, complexity, time of setup, and cost.

That leaves us with qualitative assessment. As previously stated, we use a peripheral nerve stimulator, deliver four impulses, do a twitch count, and if four twitches are present, do a TOF ratio assessment. However, the problem is that most clinicians cannot distinguish between a TOF ratio of 0.4 and 0.9. So, we make our best guess.

Some assessment sites are better than others. The best site may be the ulnar nerve site. Peripheral nerve stimulator electrodes are placed on the ulnar nerve to detect thumb movement (adductor pollicis activation). Recovery of the diaphragm and upper airway muscles occurs before that of adductor pollicis; therefore, muscle recovery at the thumb ensures sufficient recovery of all respiratory muscles. Another commonly used assessment is facial nerve stimulation of the eye muscles. However, recovery of these muscles corresponds with diaphragm recovery, but not with recovery of upper airway muscles. So, this can lead to the scenario where the patient has adequate tidal volumes while intubated, but then obstructs or has risk of aspiration after extubation.

Another issue to consider is proper placement of electrodes. To reach maximum twitch height, the black (negative) electrode should be placed distally over the ulnar

nerve near the wrist, while the positive electrode is placed more proximally over the ulnar nerve. Try to avoid placing electrodes in areas that directly stimulate muscles or in areas far from the nerve desired.

## What About Clinical Assessment of Neuromuscular Blockade?

Many practitioners (>50%) still use clinical assessment as the sole assessment to evaluate the adequacy of recovery from NMB. These tests include a 5-second sustained head lift and assessment of grip strength. Alternatively, adequate tidal volumes (5 mL/kg) and negative inspiratory force have been used as indicators of adequate reversal. However, these have not been shown to be reliable indicators of TOF greater than 0.9. For example, several studies have shown that many patients are able to maintain a 5-second head lift despite having TOF ratios <0.50. Alternatively, you may have a patient who is adequately reversed, but just too sedated to cooperate with clinical tests. Thus, clinical tests are not very sensitive tests of residual NMB. The sensitivity of these clinical tests is 20% or less. As a consequence, a patient may be moving adequate tidal volumes while intubated, then obstruct after extubation.

To sum, clinical assessment provides useful information, but should not be considered to be a reliable way to evaluate adequacy of recovery from NMB. Always use a nerve stimulator, too.

## Let's Talk About Neostigmine—the Old Standard

Neostigmine was first synthesized in 1931, and began to be routinely used in the anesthesia community in the 1950s, after tubocurarine began to be used as a muscle relaxant. For decades, it has been our mainstay for reversing NMB. It has served us well, but it is not perfect.

Neostigmine inhibits acetylcholinesterase at other sites besides skeletal muscle. Cardiopulmonary muscarinic effects include bradycardia, uncommonly sinus arrest, bronchospasm, and increased bronchial secretions. Gastrointestinal effects include peristalsis leading to abdominal cramping, and nausea. Salivation is a prominent effect. These unwanted muscarinic side effects can be reduced by the simultaneous administration of an anticholinergic medication like glycopyrrolate.

Neostigmine has a ceiling effect in that once 100% of the enzyme is inhibited, you cannot inhibit anymore. Thus, giving a second dose will not hasten recovery, unless the full reversal dose was not given. If the full dose fails to adequately recover the patient's NMB, the clinician has the choice of continuing to monitor the patient and provide sedation until spontaneous recovery has occurred or administer sugammadex.

Neostigmine is a slow-acting drug. A survey of anesthesiologists in Europe and

United States asked how long it takes for neostigmine to reverse any level of neuromuscular block, and most clinicians said that you can fully reverse a block within 5 minutes. However, this is clearly untrue—it takes 10 minutes or longer. If the twitch count is three or four, 10 minutes may suffice.

However, at a TOF count of one to two, the median recovery time (to TOF ratio of 0.9) is 49 minutes for rocuronium with a range of 13 to 146 minutes. Recovery time is also affected by the type of anesthesia—it is significantly faster under propofol anesthesia in comparison to inhalational techniques. Giving neostigmine just before tracheal extubation is a poor practice and will lead to inadequate reversal and increased incidence of respiratory issues in recovery.

Why is neostigmine a slow-acting drug? It takes about 7 to 11 minutes for peak cholinesterase inhibition to occur after neostigmine administration. This will increase ACh at the NMJ, but ACh still has to compete with the NMBA molecules present. If there is a large concentration of NMBA present, the increase in ACh may not be enough to compete and reverse the block. Further recovery of function will depend on metabolism and elimination of the muscle relaxant. And this will depend on the half-life of the drug and total dose given. So these are the issues you have to deal with when you have a TOF count of 0 or 1.

If neostigmine is given after full neuromuscular recovery, it has a potential to produce neuromuscular weakness. This potential is only there when you are using big doses of neostigmine: 0.05 to 0.07 mg/kg. If you are using a nerve stimulator and cannot demonstrate fade, and you want to reverse anyway, as you should, the doses required at that point are only 0.02 to 0.03 mg/kg. With these doses, neostigmine-induced weakness does not occur.

## A Neostigmine Dosing Strategy

All muscle relaxant reversal plans should be based on neuromuscular monitoring. Again quantitative monitoring of TOF ratio would be best, but at minimum, use qualitative monitoring. The neostigmine dose range is 0.02 to 0.07 mg/kg, with a maximum dose of 5 mg in adults.

- Deep NMB (defined as TOF count 0 to 1 with or without posttetanic twitches): Reversal with neostigmine should be delayed until further spontaneous recovery has occurred.
- Moderate NMB (defined as a TOF count of 2 to 4 or a TOF ratio less than 0.4): Can be reversed with doses of 0.05 to 0.07 mg/kg.
- Mild NMB (defined as a TOF count of 4 with no obvious tactile or visual fade or a quantitative TOF ratio of 0.4 to 0.9.): Can be reversed with a smaller dose—in the range of 0.02 to 0.03 mg/kg.

If a TOF ratio is 0.9 or higher, pharmacologic reversal is theoretically unnecessary. However, one must remember that most clinicians cannot distinguish between a TOF ratio of 0.4 and 0.9. For this reason, even though you may have a TOF ratio with no perceived fade, you should still administer a low dose of neostigmine (0.02 mg/kg to be safe).

An anticholinergic agent should also be administered prior to or with neostigmine. Typically, glycopyrrolate 0.2 mg per 1 mg of neostigmine is used as these have similar onset and duration times.

## Let's Talk About Sugammadex—the New Kid on the Block

Sugammadex has been in use in Europe since 2008, and was approved for use in the United States in 2015. There was some initial delay in approval in the United States due to the FDA wanting more data on its potential for allergic reactions. It was revolutionary because it was the first selective relaxant binding drug.

As previously stated, sugammadex encapsulates rocuronium or vecuronium in the plasma. This results in a rapid removal of these blockers from the NMJ, and a rapid restoration of normal neuromuscular transmission. When dosed appropriately, it generally works in 2 to 3 minutes for all levels of neuromuscular block. This is in stark contrast to the time neostigmine may take, especially with moderate levels of block.

It is still possible to have a residual block after using sugammadex. However, if appropriate weight-based strategies are used in conjunction with neuromuscular monitoring as a guide, the incidence approaches 0%.

We can reverse deeper levels of NMB with sugammadex in comparison to neostigmine. You can reverse when TOF counts are 0 or 1, which is not really possible with neostigmine. It is even possible to reverse almost immediately after an intubating dose of rocuronium.

There are patients who have increased risk of respiratory issues if reversal is incomplete. If the patient has obstructive lung disease, sleep apnea, myasthenia gravis, or any one of the multiple causes of diminished respiratory reserve, this drug may provide more margin of safety than neostigmine.

There are some surgical procedures that require a deep blockade until the end of the procedure. Sugammadex gives us the option of maintaining deep block and then still being able to reverse when the surgeon pops her head over the drape and announces she is done.

Since sugammadex has little or no muscarinic side effects, it does not need to be administered with glycopyrrolate. This may be of benefit in patients where you want to avoid tachycardia, such as those with significant aortic stenosis or coronary artery

disease.

## Sugammadex Issues

**Sugammadex binds oral contraceptives, and women of childbearing age should be counseled about using alternative contraceptive methods for 1 week after exposure to sugammadex.**

Sugammadex has no affinity for isoquinolinium-type NMBAs (i.e., atracurium or cisatracurium). Since it will not bind these drugs, it cannot antagonize their block.

Sugammadex is substantially excreted by the kidney. Therefore, it should not be used in patients with severe renal insufficiency (creatinine clearance <30 mL/min) or renal failure. It appears to be removed by dialysis, but there is not enough data to confirm safety in this setting.

The safety and efficacy of sugammadex in pediatric patients, pregnant patients, and lactating mothers have not been established.

A minimum waiting time is necessary before administration of a steroidal NMBA after administration of sugammadex. Your options are to use either different drugs (succinylcholine, cisatracurium, atracurium), or a large dose of rocuronium. If it has been at least 5 minutes since reversal, you can use 1.2 mg/kg rocuronium, but expect a slower onset of blockade. If it has been at least 4 hours, you can go back to standard dosing (0.6 mg/kg). However, this dose may not work if there is mild to moderate renal impairment, since sugammadex clearance will be slower. In this situation, you may need to go to the 1.2 mg/kg rocuronium dose to get an effective block. For readministration of rocuronium or administration of vecuronium after reversal of rocuronium with 16 mg/kg sugammadex, a waiting time of 24 hours is suggested.

## A Sugammadex Dosing Strategy

Dosing for sugammadex is based on TOF monitoring. Actual body weight is used in calculations. 2 mg/kg is the smallest dose that is recommended at present:

- Deep NMB: If the TOF count is 0, with posttetanic twitches or TOF count is 1, administer 4 mg/kg.
- Mild to moderate NMB: If TOF count is 2–4, administer 2 mg/kg.
- In the event of a need to reverse an intubating dose of rocuronium soon after intubation, administer 16 mg/kg.

## Putting It All Together—How to Avoid Postoperative Residual Block

- Someday, we will all be using some type of quantitative neuromuscular monitor. Until

that day comes, always use a peripheral nerve stimulator for a qualitative assessment.

- Use TOF assessment during surgery to titrate your NMBA. Try to avoid total twitch suppression.
- At the end of surgery, use TOF assessment to plan your reversal strategy. If possible, do not use the facial nerve for assessment at the end of cases. We know that there are many surgeries where the arms are tucked and are unavailable to use for twitch monitoring, and the only recourse is to use the facial nerve during the surgery. However, at the end, the arms can be freed up and the ulnar nerve can then be used for a more accurate assessment.
- When the TOF count is 0 or 1, use sugammadex as reversal. Neostigmine will not reverse this depth of block. If you do not have sugammadex as an option, then you will have to wait until at least a TOF count of 2 to reverse with neostigmine.
- If the TOF count is 2, you can use either neostigmine or sugammadex, realizing that sugammadex will reverse in 2 to 3 minutes, while neostigmine may take greater than 30 minutes. If you are using neostigmine, do not let time pressure lead you to extubate a patient who is not ready.
- If the TOF count is 3 or 4, either neostigmine or sugammadex can be used reasonably.
- Any detectable fade on subjective evaluation is inadequate recovery and indicates a TOF ratio less than 0.4. If there is no detectable fade when using a nerve stimulator and performing qualitative assessment, you should still reverse (0.02 or 0.03 mg/kg), because the human eye is not capable of distinguishing whether the TOF ratio is between 0.4 and 0.9 or greater than 0.9.
- The average clinician does not recognize how long NMBAs linger. Do not get fooled into thinking that it has been a long case, and that initial dose must surely be gone by now. Use a nerve stimulator, and plan on giving at least the low end dose (0.02 mg/kg).
- Use TOF assessment after reversal to assess the adequacy of reversal. You can use clinical tests in conjunction, but do not depend on them.
- If you administer neostigmine, and the patient still is “floppy” despite what looks like no fade on the TOF assessment, administer sugammadex 2 mg/kg. We have also avoided reintubating patients who obstructed after extubation by giving sugammadex.

## TAKE HOME POINTS

- Quantitative measurement of TOF ratio and recovery of neuromuscular blockade is the gold standard. If this is unavailable, qualitative assessment should be performed instead.
- A peripheral nerve stimulator should be used to monitor adductor pollicis function via stimulation of the ulnar nerve.

- Use TOF monitoring to guide intraoperative redosing, plan a reversal strategy, and assess the degree of reversal prior to extubation.
- Sugammadex is the best choice for reversing deep or moderate neuromuscular blockade. Either neostigmine or sugammadex can be used to reverse mild blockade.

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# Opioid Conversions—It's Not Only About the Table

Melinda M. Lawrence, MD

Opioid analgesics are used routinely in the perioperative setting for the treatment of acute pain, both during surgery and postoperatively. In recent years, however, there has been a focus on re-evaluating the use of opioids and on curbing overprescribing. In many instances, patients are first prescribed opioids for an acute issue and are continued on the initial pain regimen despite resolution of the acute issue. At present, the use of opioids for chronic noncancer pain is somewhat controversial due to the fact that there is little evidence to support the practice. There is evidence that the chronic use of opioids may lead to more adverse effects and negative outcomes than benefits. Guidelines and laws at national and state levels have been put in place to limit the amount of opioids prescribed following surgery. In general, these call for physicians to utilize the least amount of opioid required for the shortest amount of time necessary. In many cases, the suggested or mandated timeframe for opioid prescriptions should not exceed 7 days, although durations may vary based on location of practice. If pain persists beyond the expected time course to resolution, then the patient should undergo comprehensive re-evaluation and referral to a specialist should be considered. Although most anesthesiologists will not prescribe or make recommendations with regard to opioids outside the inpatient realm, it is important to be cognizant of the "big picture" surrounding opioids beyond the acute setting.

Anesthesiologists treat pain and administer opioid analgesics on a daily basis and thus should have a firm grasp on the management of pain. Unique challenges may present when treating pain in the perioperative period due to NPO status, ongoing acute disease processes, and organ dysfunction that may alter dosing and medication selection. At baseline, the amount of opioid necessary to produce analgesia has significant intra- and interpersonal variability. Variability can be a result of opioid receptor individuality, differences in absorption and clearance, differences in opioid pharmacology, administration of concurrent medications, and genetic factors. Due to a variety of factors in the perioperative period, there may also be a need to change opioid delivery from

one route to another, or from one drug to another. For the aforementioned reasons, opioid conversions can be a daunting task if one is without a point of reference.

Opioid conversion tables can be used as a tool to offer some guidance, but one must not rely solely on a table. A practitioner may assume that opioid conversion tables are based on robust evidence-based medicine, but that is not the case. Opioid conversion tables are mostly derived from expert opinion or single-dose studies of patients with acute noncancer pain, rather than rigorous science and research. Opioid conversion tables must be combined with clinical judgment and thorough consideration of the individual patient at hand.

Opioid medications are delivered by all possible routes: topical, transdermal, transmucosal, oral, rectal, and parenteral (subcutaneous, intramuscular, or intravenous). They bind to Mu, Delta, and Kappa types of opioid receptors in the central and peripheral nervous systems to cause analgesia and certain untoward side effects. Opioid affinity for Mu-receptors is one factor that determines the drug potency. Many of these receptors are specifically located in lamina II of the dorsal horn (substantia gelatinosa). (This is a fact that frequently shows up on exams!) The opioid table (Table 77.1) can be referenced for conversions between different opioids and routes.

## Opioid Conversions in Perioperative Setting

Opioids are used every day for the treatment of pain in the intra- and postoperative setting. Most commonly, pain medications are given intravenously (IV) in intermittent bolus dosing or administered directly by the patient through an IV infusion pump (IV-patient-controlled analgesia or IV-PCA). An IV-PCA allows the patient to activate a button to deliver a specified amount of drug into their IV line. Once the pump is activated, it is programmed to have a "lockout" period which is a predetermined time in which no further demand doses are delivered (lockout interval). Physicians can also program a maximum 1-hour cumulative dose that serves as an additional line of safety. Common IV-PCA regimens for opioid-naive patients are described in Table 77.2. Furthermore, a continuous infusion mode can be added to this program to deliver a specified dose as a basal infusion. Basal infusions are generally not used in opioid-naive patients but they may be helpful for opioid-tolerant patients. Patients with acute-on-chronic or cancer-related pain issues may require a basal rate for adequate pain control. Regardless of the patient, basal infusions should be used with caution and close monitoring should be employed. Utilization of continuous pulse oximetry or continuous capnography may be considered for patients on basal infusions.

Opioid conversions in perioperative settings are required in many different scenarios. Some of the patients undergoing surgical procedures are already on opioid medications for their chronic pain management. These medications need to be taken into

consideration when planning a postoperative IV-PCA pain regimen. IV-PCA can be beneficial in any setting where oral pain management cannot be used, and it offers faster titration to effect and superior patient satisfaction. Prior to calculating the new dose of any alternate opioid, it is recommended to note the average 12- to 24-hour usage of current opioid medications. Important information can be gained by reviewing the daily opioid requirements after surgery to see how pain medication usage has been trending. Following surgery, one would expect the opioid requirements to decrease each day until resolution. If dosage remains same or is increasing, further revaluation of the patient may be necessary. Persistent or worsening pain may indicate that there is something else going on, and in such cases the patient should be re-evaluated as there may be an inflammatory/infectious or neuropathic etiology.

**Table 77.1 ■ Opioid Analgesic Guide**

| | Oral (mg) | Parenteral (mg) | Duration (h) | Peak Effect (h) | $T_{1/2}$ (h) |
|---|---|---|---|---|---|
| $MSO_4$ | 30 | 10 | 3–6 (O)<br>3–4 (P) | 1–2 (O)<br>0.5–1 (P) | 1.5–2 |
| Hydromorphone | 7.5 | 1.5 | 3–6 (O)<br>3–4 (P) | 1–2 (O)<br>0.5–1 (P) | 2–3 |
| Sustained release oxycodone | 20 | — | 8–12 | 3–4 | 4–6 |
| Oxycodone | 20 | — | 3–6 | 1–2 | 2–3 |
| Hydrocodone | 30 | — | 4–8 | 1–2 | 3.5–4.5 |
| Methadone | 10[a]<br>2–4[b] | 5[a]<br>2–4[b] | 4–6 | 1–2 | 15–30 |
| Levorphanol | 4[a]<br>1[b] | 2[a]<br>1[b] | 6–8 | 1–2 (O)<br>0.5–1 (P) | 12–16 |
| Fentanyl | — | 0.1 | 1–2 | <10 min | 1.5–6 |
| Oxymorphone | 15 | 1 | 4–6 (O)<br>3–4 (P) | 1.5–3 (O)<br>0.5–1 (P) | NA |
| Codeine | 200 | 130 | 4–6 | | 3 |
| Meperidine | 300 | 75 | 2–4 | | 3–4 |

[a]For acute pain management purposes.
[b]For chronic pain management purposes.
NA, not applicable; O, oral; P, parenteral; $T_{1/2}$, elimination half-life.

## Making Conversions Easy

Let us look at an example: Ms. Jones is taking 30 mg of oxycodone ER twice a day and 15 mg of morphine IR four times a day. The pain service is consulted for PCA recommendations because the patient can no longer take oral medication. She was admitted for acute-on-chronic back pain and may require surgical intervention pending further evaluation and workup. Now, let us work through this step by step:

**Table 77.2 ■ Common Intravenous Patient-Controlled Analgesia Regimens for Opioid-Naive Adults With Acute Pain**

| Drug (Usual Standard Concentrations) | Usual Starting Demand Dose | Usual Dose Range | Usual Starting Lockout (min) | Usual Lockout Range (min) |
|---|---|---|---|---|
| Morphine (1.0 mg/mL) | 1.0 mg | 0.5–2.5 mg | 10 | 6–10 |
| Hydromorphone (0.2 mg/dL) | 0.2 mg | 0.05–0.4 mg | 10 | 6–10 |
| Fentanyl (10 µg/mL) | 10 µg | 10–50 µg | 6 | 6–8 |

From American Pain Society. In: Ashbum MA, Lipman AG, Carr D, Rubingh C, eds. *Principles of Analgesic Use in the Treatment of Acute Pain and Cancer Pain*. 5th ed. Glenview, IL: American Pain Society; 2003:13–41.

- Calculate daily morphine equivalents:
  - Oxycodone to morphine ratio is 1:1.5 (i.e., for every 1 mg of oxycodone you need 1.5 mg of morphine).
  - Above patient takes a total of 60 mg oxycodone ER and 60 mg of morphine IR. Since oxycodone 60 mg is equivalent to 90 mg of morphine, total daily morphine equivalent dose will be: 90 + 60 = 150 mg.
- Next convert from oral to IV.
  - Morphine oral to parenteral ratio is 3:1 (i.e., for every 3 mg of oral morphine you would need 1 mg of IV morphine).
  - Therefore, 150 mg/3 = 50 mg of IV morphine per day
  - 50 mg IV per day divided by 24 hours→ ~2 mg IV morphine per hour

An increase in the total dose by 25% to 50% over the baseline use is recommended for treating moderate to severe postoperative pain in patients who are currently on opioid therapy (i.e., for at least 5 days). Subsequent changes in PCA orders should only be made after five half-life ($T_{1/2}$) periods. Thus, treatment of postoperative pain following a spine surgery in the previously mentioned patient would require approximately 2.5 to 3 mg of IV morphine per hour. Half of this dose can be safely administered as basal infusion, with the remaining provided as demand doses with suitable lockout intervals. Some dose adjustment to decrease daily requirement may be

considered since the underlying source of pain may be corrected after surgery. In those patients who have been on short-term opioids (i.e., therapy less than 5 days), only a 10% to 20% increment is recommended when upping the dose to treat significant postop pain.

When switching from one opioid medication to another, the tolerance that exists to the currently prescribed opioid may not apply to a new opioid when switched, a concept known as incomplete cross-tolerance. An example of when this issue is relevant is when you are converting from one opioid providing adequate analgesia but unacceptable side effects (nausea, itching, etc.) to a different opioid. In this circumstance, conversion of one opioid to another requires a reduction in the total dose of new opioid by 25% to 50% to compensate for incomplete cross-tolerance and to avoid overdose. (However, if the previous pain control was not adequate, then you might not reduce the dose as much.) Again, half of this dose may be given as basal infusion and the remainder as demand doses. It is important to understand that due to significant interpersonal variations, a "one size fits all" technique would lead to both physician and patient dissatisfaction. After a therapy is initiated, regular pain assessments should be made, and treatment should be titrated accordingly.

Fentanyl patches are a unique issue and are typically managed in one of two ways in the perioperative period. Patches can either be removed or continued and both strategies are reasonable. There are issues with both removal and continuation that must be considered. If the patch is continued and the patient has elevated body temperature or if an intraoperative warmer is used, heating of the patch may lead to variable delivery of the medication, usually more than expected. An advantage to continuing the patch is that it takes away the need for a basal rate on the PCA. If discontinuing the patch, it may take 17 hours or more for a 50% decrease in serum fentanyl concentrations. The ongoing effect of a transdermal fentanyl patch must be taken into consideration in the first day after patch discontinuation.

A long-acting or extended-use opioid such as a fentanyl patch should not be considered for the treatment of acute pain. If you choose to initiate use of a fentanyl patch, a good resource to consult is the reference provided by the manufacturer. This reference includes recommended fentanyl doses based on daily oral morphine requirements (Table 77.3). However, be careful when using this table to convert from fentanyl back to oral morphine equivalents because it recommends a range of morphine dosing. For example, a patient receiving 50 μg/hour of transdermal fentanyl corresponds to 135 to 224 mg of oral morphine (mean = 180 mg). This range can now be used to convert to any other opioid drug or route using the standard method, as previously described. A conservative practice would be to use the lower end of this range, and then adjust the dose further based on the patient's response. Alternatively, practitioners

choose to use the mean of the range (180 mg in this case). The equivalent IV morphine PCA dose to the 50 µg/hour of transdermal fentanyl would then be 60 mg morphine/24 hours. When switching from a fentanyl patch to oral morphine, another commonly utilized strategy is to use the following conversion: 2 mg of oral morphine equates to 1 µg/hour of transdermal fentanyl. The variation in conversions to start a fentanyl patch is a good example of why opioid tables are not absolute, and medication dosing may differ from patient to patient depending on the unique factors of the patient at hand.

**Table 77.3 ■ Recommended Initial Transdermal Fentanyl Dose Based on Daily Oral Morphine Dose**

| Oral 24-h Morphine Dose (mg/d) | Transdermal Fentanyl Dose (lg/h) |
|---|---|
| 60–134 | 25 |
| 135–224 | 50 |
| 225–314 | 75 |
| 315–404 | 100 |
| 405–494 | 125 |
| 495–584 | 150 |
| 585–674 | 175 |
| 675–764 | 200 |
| 765–854 | 225 |
| 855–944 | 250 |
| 945–1,034 | 275 |
| 1,035–1,124 | 300 |

## Opioid Conversions From Intravenous to Oral Form

Conversion of parenteral opioids to oral formulation is based on similar principles, but may pose certain unique problems. Often, these calculations are requested by the surgical team at the time of the patient's discharge. Any overestimation with these calculations may impose unwanted side effects on the patient. It is essential to teach the surgical teams in your hospital that these steps should be taken at least 24 to 48 hours prior to the patient's discharge, which is usually a sufficient time to assess the patient's response to the new medical regimen. A basic guide for these conversions is shown in

Figure 77.1. For acute pain management, long-acting and extended release formulations should generally be avoided, especially in opioid naive patients. As the pain-inducing injury (surgical wound) heals, lesser amounts of short-acting medications will be used by the patient and they should be tapered off as soon as possible. On the other hand, more aggressive conversions and escalation may be appropriate for use in cancer pain. In these cases, long-acting and extended release opioids would be reasonable.

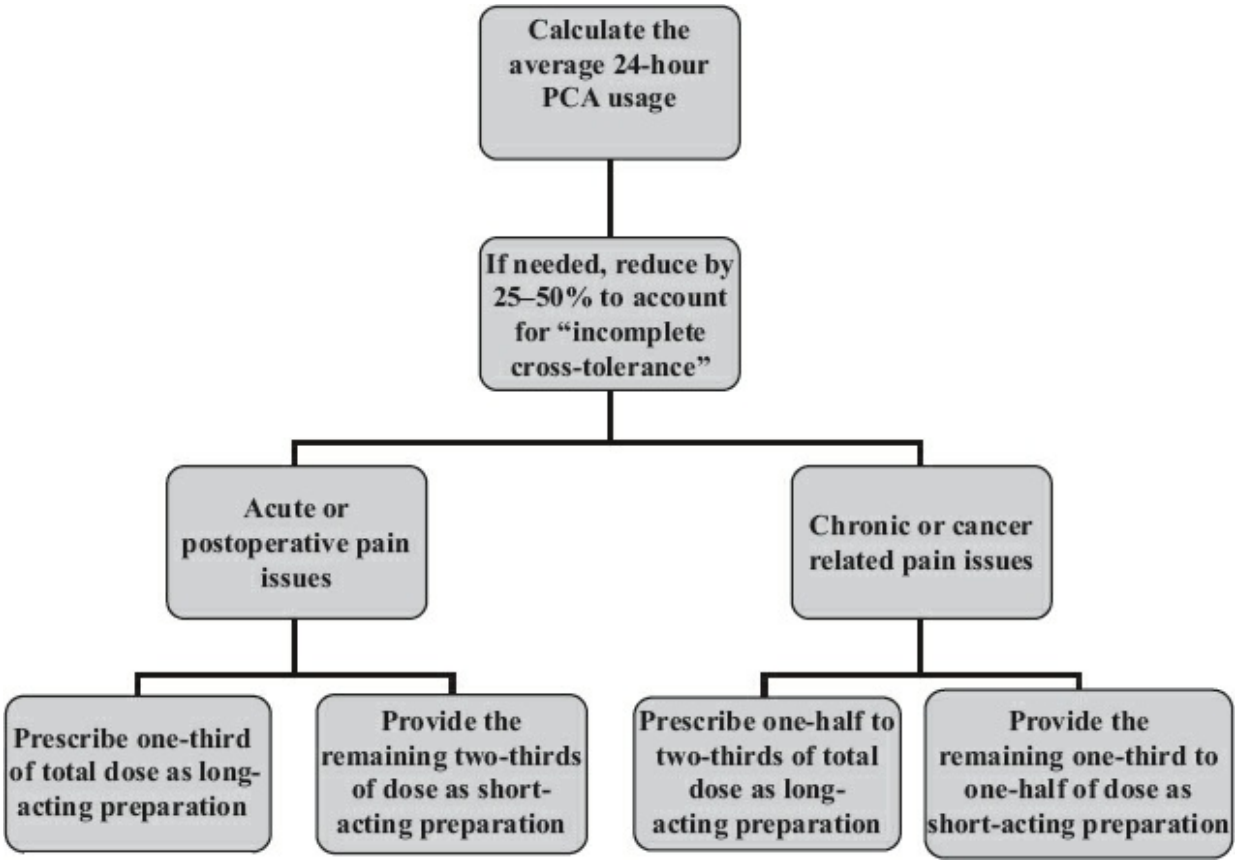


**Figure 77.1.** Changing the parenteral opioid dose to oral form and conversions between opioids.

## TAKE HOME POINTS

- Opioid medications in the perioperative setting are appropriate but they should be used at the lowest dose to adequately treat pain and continued for the shortest amount of time necessary.
- Opioid tables may be used as a guide but are not "one size fits all."
- Avoid use of long-acting or extended release opioids for the treatment of acute pain.
- The safety of these calculations can be enhanced by initially accepting the conservative side of dose range and later adjusting the dose according to the patient's response.
- When in doubt, always err on the side of caution and re-evaluate often to assess pain

control.

- Physicians should also be prepared to recognize and manage any possible side effects or add adjuvant medications to the regimen when needed.

## Suggested Readings


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# Not All Patients Are Naive—Management of Perioperative Pain in Opioid-Dependent Patients

Melinda M. Lawrence, MD

Medical science has witnessed a dramatic shift in the awareness and treatment of chronic pain over the past few decades. New drug development for the treatment of pain, a call for increased awareness of pain, and literature suggesting that opioid medications are safe to use chronically for pain (Porter and Jick, Portenoy) created the perfect storm and are some of the factors that led to what many call the "opioid crisis." MS Contin was released in the late 1980s followed by Oxycontin in the mid-1990s. Also in the mid-1990s, the American Pain Society developed the idea of promoting "pain as the fifth vital sign." The "vital sign" concept came from the desire to increase awareness of the importance of proper assessment and treatment of pain. Trying to ensure that our patients do not suffer from pain is a great idea, but there were some unforeseen consequences down the line. For years, hospital reimbursement was tied to adequate treatment of pain, which was assessed by patient survey after discharge. There is evidence to show that these changes did not result in improved quality of pain management. These changes did result in more opioid prescribing and more opioid-related deaths. (In 2017, hydrocodone/acetaminophen was the most popular drug prescribed in the United States!) I practice in Ohio, a state where unintentional drug overdose is the leading cause of injury-related death (a category that also includes fatal falls, car accidents, drownings, and homicides). Some of the issues in our state have been curbed by legislation for opioid prescribing, opioid guidelines, and the required use of a controlled substance prescription reporting system. However, that still leaves us with the problem of dealing with all the patients who take unprescribed illicit street drugs like heroin.

Due to the aforementioned, it is highly likely for anesthesiologists to encounter patients who are taking some form of opioid (prescribed or not prescribed/illicit). In addition, more patients are being encountered that have a history of abuse and are maintained on medications like buprenorphine/naloxone ("Suboxone") or naltrexone,

which may require specialized management in the perioperative period. Lack of knowledge, bundled with uncertainty about opioid dose requirements, and possibly unrealistic expectations of patient and family certainly make these cases challenging. Many patients have the expectation that their pain should be 0/10 (whether acute or chronic) or that pain medications equate to opioid medications, neither of which is true. Setting goals, reviewing expectations, and outlining the plan of care with the patient and care team can help get everyone on the same page. These difficult situations can be handled with poise by knowing some fundamental principles related to the perioperative care of chronic opioid-tolerant patients.

## Preoperative Evaluation

Anesthetic care of those patients who take opioids regularly should begin with early recognition of this issue and formulation of a clear plan. A preoperative visit allows the anesthesiologist to perform a thorough medical evaluation, outline a postoperative pain management plan, and advise on the potential treatment options. Detailed information about the patient's opioid and adjuvant medication doses should be gathered. It is imperative that the anesthesiologist maintain a kind and nonjudgmental manner during any patient interviews. A good way to start the conversation with the patient is to say just that—you are not there to judge but just to gather as much information as possible so that the patient's perioperative pain is managed successfully. Consider getting an electrocardiogram in patients on high doses of methadone or on tricyclic antidepressant medications since these can sometimes be associated with QT interval prolongation. A prolonged QT interval can predispose a patient to ventricular tachycardia, ventricular fibrillation, or torsades de pointes, and must be identified. Another issue to consider are the gastrointestinal effects of opioids. Some of these patients will have delayed gastric emptying or gastroesophageal reflux disease, which may theoretically increase the risk of aspiration during general anesthetic induction and intubation. Patients who take illicit drugs may have issues with hypertension and dilated cardiomyopathy, infectious diseases such as hepatitis and HIV, and may have difficult IV access.

A detailed discussion should be had with the patient to address his or her anxieties and fears. Patients are often worried about excessive pain following the surgery, which is frequently a reflection of their previous experiences. Anesthetic management options should be discussed. Whenever possible, a regional anesthetic technique should be recommended and explained to the patient. They should also be advised to continue their analgesic regimen, including taking their normal morning dose on the day of surgery, to prevent any withdrawal or falling behind on opioid requirements.

## Anesthetic Management

Patients should be advised to arrive early on the day of surgery. After evaluation of the patient, appropriate pre-emptive or preoperative analgesia should be given. Oral acetaminophen (1 g orally 1 to 2 hours preop) is acceptable in almost all patients (the one caveat might be significant liver disease). A nonsteroidal anti-inflammatory drug (NSAID) (such as celecoxib) should also be considered, as long as there are no surgical or medical contraindications. Another strategy is to administer gabapentin 600 mg oral 1 to 2 hours preop. The anesthetic plan should again be discussed in detail with the patient, and regional anesthesia should be considered whenever feasible.

Regional techniques have been described for virtually all locations in the body. As an extreme example, we have managed acute and chronic facial and eye pain with intrathecal drug delivery of local anesthetic and opioid. In a couple of cases, we have had patients who could not discontinue their maintenance naltrexone therapy for a multilevel lumbar surgery due to a high risk of relapse, and their postop pain was managed with zero opioid by using nonnarcotic analgesics and an epidural with local anesthetic. There is almost no anatomical limitation to regional anesthesia but placement of a catheter or block to cover certain regions may be challenging. Coordination between the acute and chronic pain service as well as the use of fluoroscopy-guided catheter placement may be necessary in some cases.

When a general anesthetic is being used, a long-acting opioid like hydromorphone can be titrated in prior to incision. Ketamine, an NMDA receptor antagonist drug, is useful in that it provides good analgesia and reduces postoperative opioid usage in opioid-dependent patients. A typical ketamine regimen would include an IV bolus of 0.5 mg/kg prior to incision, followed by an infusion at 5 μg/kg/minute. (An easy way to set this up on a syringe pump is to mix 50 mg of ketamine in 50 mL of saline). Clonidine and dexmedetomidine (alpha-2-adrenergic agonists) have also been shown to have similar effects. If oral acetaminophen was not administered preoperatively, consider giving 1 g of acetaminophen by rectal or IV routes. If celecoxib was not administered preop, consider IV ketorolac (15 to 30 mg). This should be discussed with your surgeon —since there are some surgeries where it may be contraindicated (fractures and fusions), and sometimes there are concerns about bleeding. Last, but not the least, the surgical team should be encouraged to infiltrate a long-acting local anesthetic solution at the site of incision.

Intraoperative narcotic requirements in the opioid-dependent patient may be as much as 50% to 300% higher than in an opioid-naive patient for a similar surgical procedure. When a patient is under general anesthesia, a useful strategy is to reverse muscle relaxants early, and allow the return of spontaneous ventilation. IV opioids can then be titrated to achieve a respiratory rate of 12 to 14/minute prior to extubation.

There have been some reports that excessive doses of fentanyl can be delivered from

a transdermal fentanyl patch when a warming blanket is placed on the patient. Heating a transdermal fentanyl patch can increase the rate of fentanyl delivery. Also, avoid placing warming devices over the site of recently removed fentanyl patches because you can similarly see increased uptake from the dermal fentanyl "depot." Heating blankets can still be used as long as patch sites are insulated from the heat, and the patient's body temperature is not allowed to climb above normal.

## Postoperative Pain Management

As expected, postoperative pain management can be difficult in these patients (unless a regional block is used). Unfortunately, intraoperative opioid usage does not help in estimating postoperative opioid requirements. Continuous regional techniques certainly come in handy in these patients. If an epidural technique is used, a local anesthetic in combination with an opioid should be used. Regional techniques can be supplemented with intravenous patient-controlled analgesia (IV-PCA) with a moderate demand-only dose if additional analgesia is required. When regional techniques are not an option, an IV-PCA (with basal infusion and a moderately higher demand dose) should be considered as the next best choice. Patient's preoperative total opioid usage should be taken into account while prescribing PCA basal infusion. These oral-to-IV opioid conversions are discussed in Chapter 75. A two- to four-fold increase in opioid requirement should be expected in the postoperative period in comparison to that used by an opioid-naive patient. The patient should be monitored in the PACU for oversedation or respiratory depression, and frequent evaluations should be done to ensure timely adjustments in PCA settings (whether epidural or IV). Acetaminophen and NSAIDs should also be continued during the postoperative period. The patient should ideally be followed by either the acute or chronic pain service, depending on institutional preferences.

## What About Patients on Maintenance Therapy?

As previously discussed, it is becoming more common to see patients on maintenance therapy to treat opioid addiction/dependence and prevent relapse. Example therapeutics include buprenorphine alone ("Subutex") or products containing buprenorphine and naloxone ("Suboxone"). Buprenorphine is a semisynthetic partial mu receptor agonist and it has a very high affinity and slow dissociation from mu opioid receptors. Because of efficient metabolism in the liver (the first pass effect), buprenorphine is largely ineffective if swallowed, and so is typically administered either transdermally or sublingually. The buprenorphine/naloxone combo was conceived as a deterrent to attempts to alter (snort, inject, crush) a buprenorphine sublingual tablet. Naloxone, a pure opioid antagonist, has no absorption when taken sublingually, but would

precipitate withdrawal if snorted or injected. Since buprenorphine has a high affinity at the mu receptor, small doses of opioids will not produce the normal expected analgesia. However, it is possible to use larger doses of opioids to "overcome" the effect produced by buprenorphine at the receptor level.

There are several strategies for managing patients who take maintenance therapy, and it is important to identify these patients in advance and develop a well thought out plan when elective surgery is to be scheduled. A discussion with the patient, surgical team, and addictionologist is usually necessary. For minor surgeries patients may continue their maintenance medications. In other instances, their maintenance medication dosages may be increased or altered for pain control. For more major surgeries, buprenorphine/naloxone may be discontinued 3 to 5 days prior, and the patient is bridged with an opioid agonist to prevent withdrawal. If a patient has a very high risk for relapse of their opioid addiction, it is possible to continue maintenance therapy throughout the perioperative period if there is aggressive pain management with nonopioid medications in combination with regional anesthesia. Restarting the maintenance therapy is usually determined by the prescribing physician. In urgent or emergent situations, multimodal analgesia and regional anesthesia is recommended. If regional anesthesia is not possible, large doses of IV opioids may be necessary to manage the patient's pain. In this scenario, continuous monitoring with either pulse oximetry or capnography should be considered.

## What About Patients Previously Opioid-Dependent or Addicted?

You will have patients present for surgery who were formerly opioid-addicted or opioid-dependent and are no longer on opioids, but are concerned (even afraid!) of getting addicted or dependent again. Unfortunately, they are probably correct—they do have a higher risk—although it is hard to quantify. You will see stories in the media about patients who were previously addicted, got clean, then relapsed or overdosed after having a surgical procedure.

If one of these patients presents for urgent surgery, it is usually reasonable to follow the practices previously described—which is to use regional anesthesia techniques when possible, multimodal analgesic techniques, and opioids as needed. (This is assuming they are not on maintenance therapy with buprenorphine or similar drug.) However, these patients will benefit from close followup with a chronic pain and/or addiction specialists. These are not patients that you want to wish good luck to and send them out into the wild.

On the other hand, if one of these patients shows up for preoperative evaluation for a planned future surgery, there is more time to prepare, get expert input, and have some

frank discussions with the patient regarding pain control options—the risks, benefits, and alternatives. The discussion can be expanded to include input from pain and addiction specialists (no shame in asking for expert help!). Family involvement may be helpful if allowed by the patient—they can reinforce the plan of care with the patient in the postop period.

In many cases, the post discharge period is the danger time, especially if opioids are continued after the patient leaves the hospital. The plan should be to limit prescriptions to the lowest dose to treat pain for the shortest amount of time. In some instances, patients with an abuse history may go into a facility after surgery (rehab or skilled nursing) where the patient's opioids are held and administered by the facility, rather than trusting the patient to control their own pain meds. Another strategy is to have a designated person who lives with the patient control and administer the postop opioid as prescribed. Whenever a prolonged course of opioids are continued after surgery, close followup by a specialist and frequent reassessment of the pain is recommended along with controlled substance agreements, controlled substance pharmacy reports, and urine drug testing (looking for presence or absence of prescribed drug and/or presence of illicit or nonprescribed drugs).

In my practice, a good example would be the management of patients with complex regional pain syndrome (CRPS). Upon diagnosis I tell all patients that if they plan to have further surgery, we should discuss the plan of care for pain management before surgery. For these patients I typically recommend multimodal analgesia along with neuraxial anesthesia with or without opioid. If a prolonged course is expected, a tunneled catheter can be placed (sometimes left for weeks to months to allow for rehab, though weekly inspection of catheter site is required). The overall plan of care I employ for my CRPS patients can be used for any patient and would allow for opioid avoidance if the patient desires. Pain medicine is elective and the patient has the right to decline. The anesthesia provider is addressing the balance of two clinical situations: one is that no one dies from pain (it just might feel that way). The other is that refusal of pain medications may impact the patient's ability to mobilize, ambulate, and rehab in the postoperative period and potentiate tachycardia, hypertension, and greatly increased perioperative stress hormones (and that can kill a patient). But after all, that is why we get up in the morning—to balance the risk-benefit ratios.

## TAKE HOME POINTS

- Perioperative pain management in opioid-dependent patients can be challenging.
- A preoperative visit certainly helps address many issues, including patient's concerns.

- Preoperative or pre-emptive analgesia is an important step leading to reduction in postoperative opioid requirements.
- Whenever possible, regional techniques should be used for intraoperative and postoperative management.
- Adjuvant medications such as acetaminophen, NSAIDs, ketamine, and α2-adrenergic agonists also help reduce opioid requirement in this difficult population.
- Close followup by acute and chronic pain management teams as well as addiction medicine is warranted to ensure best postoperative care in opioid-dependent patients.

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79

# The Basal Infusion Mode in Patient-Controlled Analgesia Is Both Friend and Foe

Amit Sharma, MD

Patient-controlled analgesia (PCA) is the core therapeutic drug delivery system in acute and acute-on-chronic pain settings. Historically, in 1971, Sechzer published the first report showing the safety and efficacy of delivering small incremental doses of opioids using a machine. Since his initial description, this novel technique of analgesic drug delivery has been enormously refined and widely accepted. It emanated from the basic pharmacologic principle that a given analgesic medication needs to attain a specific serum concentration to produce analgesia. The lowest drug levels at which this is accomplished is the minimum effective analgesic concentration (MEAC) of that particular drug. Maintaining a constant serum drug concentration above MEAC would thus result in sustained analgesia. It is almost impossible to achieve stable serum drug levels with intermittent oral and intramuscular drug delivery methods. They often result in peaks of high drug concentrations that cause side effects and troughs of lower drug levels leading to inadequate analgesia (Fig. 79.1). These variations in drug levels can be avoided with the use of intermittent small intravenous (IV) doses or a continuous infusion.

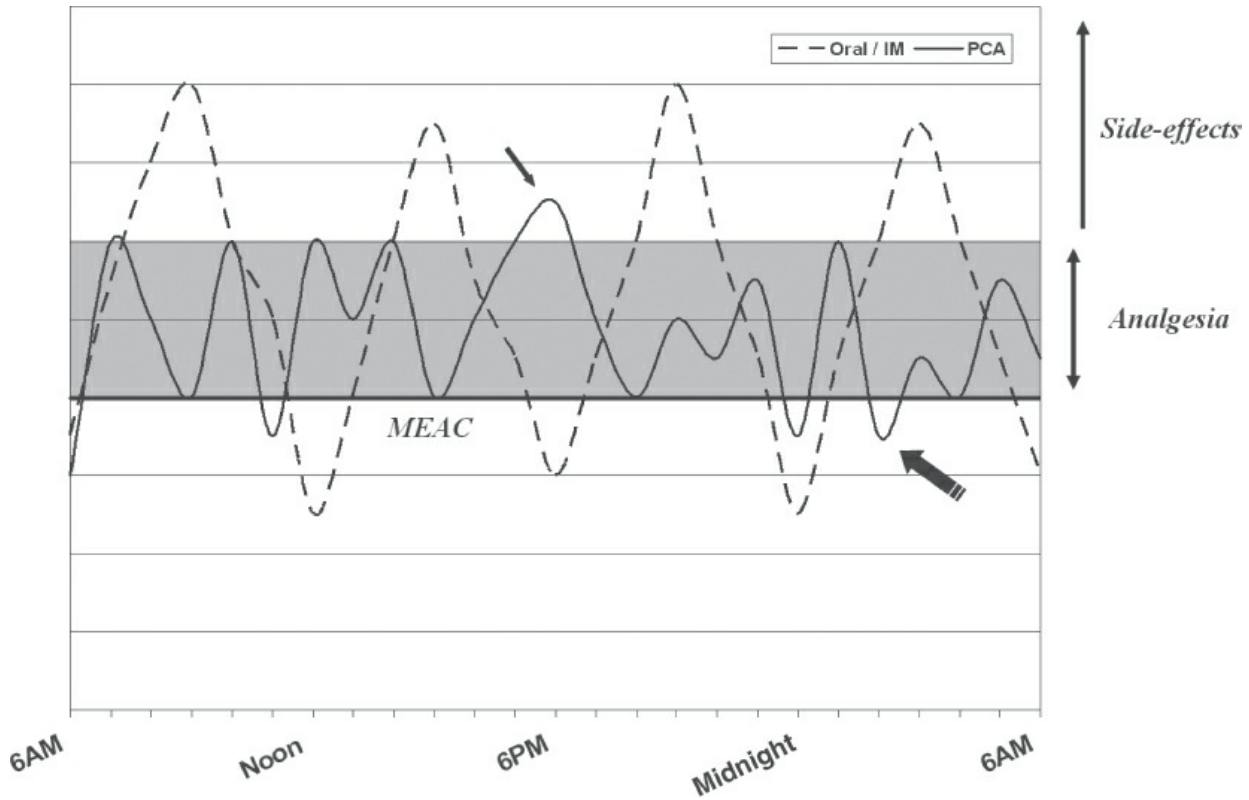


**Figure 79.1.** Comparison of systemic drug concentrations (y axis) during conventional oral or intramuscular (IM) opioid drug delivery system and during patient-controlled analgesia (PCA) use. The dark line demonstrates the minimally effective analgesic concentration (MEAC), and the shaded area represents the analgesic window. Serum drug concentrations above the analgesic window (thin arrow) result in clinically relevant side effects, while those below (bold arrow) cause poor pain control.

Using these principles, opioids are now often delivered intravenously using highly sophisticated microprocessor-controlled units (e.g., PCA machine) in numerous acute and certain selected chronic pain settings. These machines allow several modes of drug administration, some of which are as follows:

) **Demand-Only Mode (DOM):** This is the most commonly used method. The patient can self-administer a fixed dose (demand dose) into their IV.

) **Continuous Plus Demand Mode (CDM):** A fixed baseline (basal or background) dose is infused intravenously every hour in addition to demand dosing.

) **Variable-Rate Infusion Plus Demand Mode (VID):** In addition to patient dosing, continuous basal rate is preprogrammed on an internal clock to vary, turn on, or turn off during specified hours of the day.

) **Variable-Rate Feedback Infusion Plus Demand Mode (VFID):** Basal infusion rate is varied by the PCA machine's microprocessor and is based on patient's usage.

Given the widespread use of PCA in postoperative settings, it is imperative for all anesthesiologists to have a precise understanding of their functioning. Although standard PCA guidelines exist for postoperative analgesia (Table 79.1), confusion often prevails with regard to basal infusion. Proponents of basal infusion claim that it allows better patient satisfaction because the demand frequency with CDM is lower than in DOM. It seems that the constant IV infusion of opioid would maintain a certain level of serum drug levels and would then be easier to reach the MEAC using fewer demand doses (Fig. 79.2). In reality, this perception is oversimplistic and does not account for multiple variables on which drug pharmacokinetics actually depends. For instance, the serum drug concentration required to reach MEAC varies from one individual to the next. This situation is further complicated by the fact that significant interpersonal variability exists for the safe analgesic window, which is defined as the serum drug concentrations that are associated with clinically relevant analgesia without any side effects (shaded area in Fig. 79.1). Certain individuals, such as elderly people, have relatively narrow analgesic windows, and use of basal infusion would pose undue risks for side effects in these patients.

**Table 79.1 ■ Relevant Trials Comparing IV PCA Demand-Only and Continuous Plus Demand Mode**

| Study, Year | Type of Study Method | Results |
|---|---|---|
| Guler 2004 | Randomized controlled trial<br>60 adults undergoing elective CABG surgery<br>IV morphine PCA: DOM versus CDM<br>Follow up: 24 hrs postoperative | Similar sedation scores in both groups<br>CDM group had<br>✓ Significantly lower VRS scores after first hour<br>✓ Greater cumulative morphine consumption<br>✓ No episodes of hypoxemia or hypertension |
| Dal 2003 | Randomized double-blind trial<br>35 adults patients undergoing elective open heart surgery<br>IV morphine PCA: | ✓ Less morphine consumption at 44 hrs in DOM ($p = 0.0006$)<br>✓ No significant difference between two groups in VAS scores, blood levels of morphine, and adverse effects |

| | | |
|---|---|---|
| | DOM versus CDM<br>Follow up: 44 hrs postoperatively | |
| Russell 1993 | Controlled trial<br>62 patients undergoing gynecologic surgery<br>IV morphine PCA: DOM versus CDM (1 mg/hr)<br>Follow-up: VAS scores and $SpO_2$ for 24 hrs postoperatively | ✓ Significant increase in total morphine consumption in CDM<br>✓ Similar pain scores in both groups<br>✓ No difference in severity of postoperative desaturation between two groups |
| Parker 1992 | Randomized controlled trial<br>156 adult women undergoing elective abdominal hysterectomy<br>IV morphine PCA: DOM versus CDM (POD 0—continuous infusion of 1 mg/hr, POD 1–2—nighttime infusion, 10 pm–8 am) | ✓ No improvement in patient's ability to sleep or to rest comfortably at night<br>✓ Similar numbers of patient demands and supplemental bolus doses, opioid usage, and recovery parameters in the two treatment groups<br>✓ CDM group had six programming errors; in addition, therapy was discontinued in three patients due to hemoglobin oxygen desaturation |

CABG, coronary artery bypass grafting; CDM, continuous plus demand mode; DOM, demand-only mode; IV, intravenous; PCA, patient-controlled analgesia; $SpO_2$, oxyhemoglobin saturation; VAS, visual analog scale; VRS, verbal rating scale.

The futility and risks of basal infusion, especially in opioid-naïve patients, has been shown in multiple studies (Table 79.2). Guler et al. showed significant improvement in pain scores with the use of CDM technique in the postoperative pain setting, but most other studies have failed to replicate those results. Even with similar analgesic response, opioid consumption has been shown to be higher with CDM than with DOM in numerous studies. Moreover, the low-dose continuous nighttime-only infusion (VID mode) failed to show any improvement in patients' sleep or comfort in most studies

(Table 79.2). CDM technique in these studies failed to show any major increase in the incidence of severe side effects. Other studies and case series, in contrast, have frequently linked the additional background opioid infusion to myriad side effects. Some of the feared complications include respiratory depression and higher chances of programming errors.

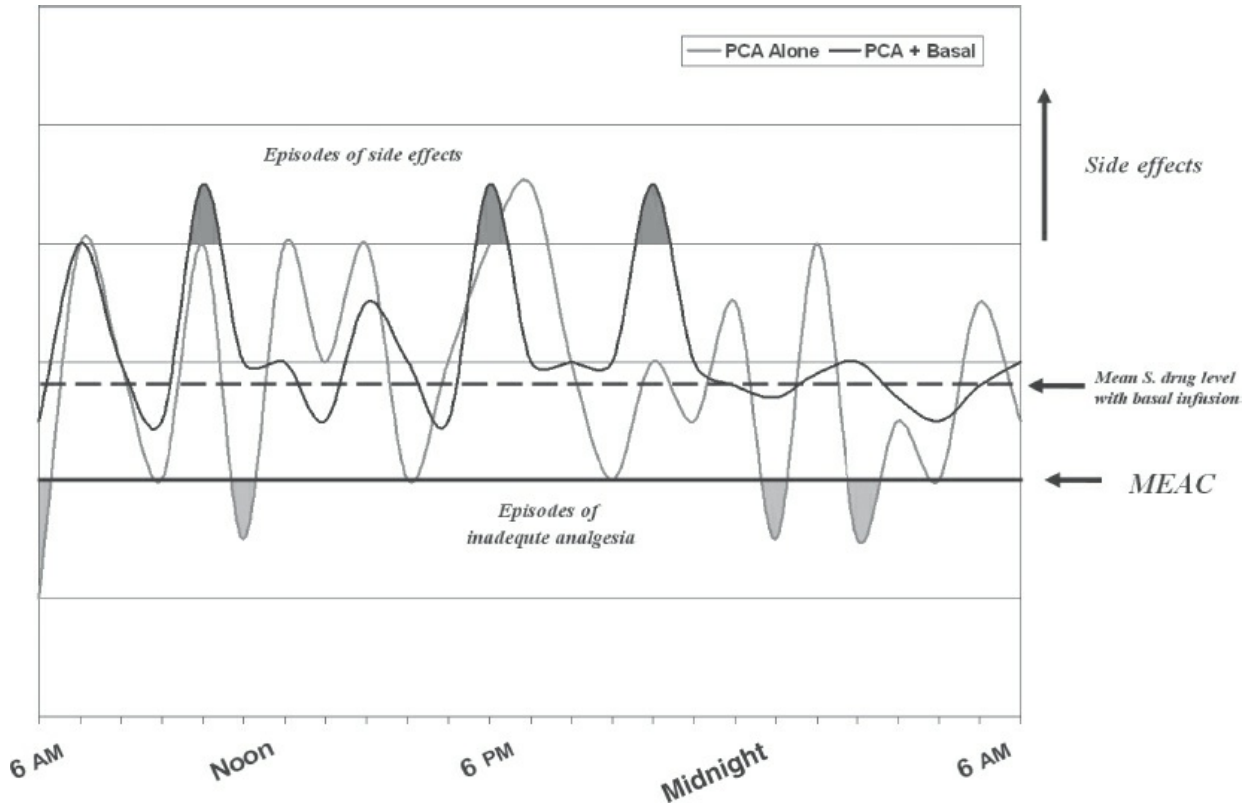


**Figure 79.2.** Optimum use of basal infusion during opioid drug delivery using a patient-controlled analgesia (PCA) system. Under ideal situations, continuous basal infusion raises serum drug concentrations closer to or above minimally effective analgesic concentration (MEAC) (dotted line). This may reduce the number of demand doses required to stay in the analgesic window and may reduce the episodes of inadequate analgesia. As evident, it may also increase the chances to develop clinically relevant side effects.

Despite additional risks, use of continuous basal infusion is recommended for opioid-tolerant patients by some authors and is frequently used in cancer patients in clinical practice. It can also be a handy tool in the presence of certain personality traits and some neurologic disorders. One of the important prerequisites of PCA usage is the patient's willingness and capacity to self-administer demand doses at appropriate times. Patients with external locus of control, severe depression, and learned helplessness are often unable to use the demand doses adequately. Also, patients with neurologic problems such as Parkinson disease or motor neuron diseases might find the use of the demand button challenging. A low-dose basal infusion can be slowly titrated in these subgroups with improved results. Caution is certainly advised in all patients whenever

basal infusion is being considered. Risk factors for respiratory depression with IV PCA usage include age older than 70 years; presence of renal, hepatic, pulmonary, or cardiac impairment; obesity and sleep apnea (suspected or history); use of concurrent central nervous system depressants; and upper abdominal or thoracic surgery. Basal infusion should be avoided in these patients, whenever possible.

**Table 79.2 ■ Intravenous Opioid Patient-Controlled Analgesia Guidelines for Opioid-Naive Adults With Acute Pain**

| Drug (Usual Standard Concentrations) | Usual Starting Demand Dose | Usual Dose Range | Usual Starting Lockout (min) | Usual Lockout Range (min) |
|---|---|---|---|---|
| Morphine (1.0 mg/mL) | 1.0 mg | 0.5–2.5 mg | 10 | 6–10 |
| Hydromorphone (0.2 mg/dL) | 0.2 mg | 0.05–0.4 mg | 10 | 6–10 |
| Fentanyl (10 mcg/mL) | 10 µg | 10–50 µg | 6 | 6–8 |

From American Pain Society. *Principles of Analgesic Use in the Treatment of Acute Pain and Cancer Pain.* 5th ed. Glenview, Ill.: American Pain Society; 2003;20.

The concept of PCA involves the administration of drug based on the patient's demand. It also applies to alternative routes of drug delivery, such as transdermal, subcutaneous, oral transmucosal, epidural (patient-controlled epidural analgesia [PCEA]), intrathecal, and regional (patient-controlled regional analgesia [PCRA]). Although this chapter mainly focuses on IV PCA basal infusion, similar notions can be extrapolated to these alternative modes of drug delivery, with few exceptions. In general, for postoperative pain control, demand dose systems using local anesthetic and an opioid combination (PCEA and PCRA alone) provide similar analgesic response with superior patient satisfaction rates when compared to continuous infusion techniques. They also require fewer interventions by nursing staff and acute pain team members. However, addition of a small-dose continuous infusion along with demand boluses has been shown to reduce total anesthetic consumption with similar analgesic results. It is thus recommended that PCEA and PCRA management should be optimized with the addition of a low-dose basal infusion on a routine basis.

## TAKE HOME POINTS

- PCA is being universally employed to enhance analgesia in acute and certain chronic pain conditions.
- Overall, PCA with DOM provides better pain control with no worsening of side effects when compared to intermittent intramuscular or oral regimen.

- In opioid-naive patients, use of background or basal infusion leads to increase in opioid consumption with no significant improvement in pain control.
- Basal infusion can be effectively used in the presence of opioid tolerance, certain complex personality traits, and neuromuscular diseases, as well as in cancer-related pain states.

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80

# Keep Discussing the Use of Ketorolac (Toradol) With Your Surgical Team Before the Need Arises and Keep Your Eye on the Literature

Catherine Marcucci, MD, Amit Sharma, MD, and Wayne T. Nicholson, MD PharmD

**"In a fight between an anesthesiologist and a surgeon, the patient is always defeated."**

It was another fine morning. We were finishing our first scheduled laparoscopic urologic surgery case when I received a Stat page to the operating room (OR). As I was reaching the OR, I could hear our famous urologist roaring at my resident. Apparently, my patient-compassionate resident had used ketorolac (Toradol, 30 mg IV) for postoperative pain control, and our surgical friend firmly believed that it would lead to renal failure or postsurgical bleed. I tried dodging his logic of so-called experience with my shield of scientific data leading to more noise pollution in the OR. The end result of our battle for Middle Earth was the formulation of the Eleventh Commandment by our respected colleague: "NO TORADOL for any of my patients EVER." Currently, ketorolac is perhaps one of the leading causes of tense anesthesiologist–surgeon relationships, and it is briefly discussed in this chapter.

## Basic Pharmacology

Ketorolac tromethamine (commercially available as Toradol) is a member of the pyrrole–pyrrole group of nonsteroidal anti-inflammatory drugs (NSAIDs). It is available for intravenous (IV) or intramuscular (IM) administration as 15 mg in 1 mL and 30 mg in 1 mL (60 mg in 2 mL) solution. It is also available in tablets of 10 mg for oral use. It is a peripherally acting analgesic agent that inhibits prostaglandin synthesis. The drug possesses no sedative properties, making it a good agent in the perioperative setting. The bioavailability with oral, IM, or IV use is 100%, with peak analgesic activity time of 2 to 3 hours via oral route and 1 to 2 hours when used parenterally. Ketorolac is highly protein bound, metabolized in the liver via hydroxylation and

conjugation, and eliminated by the kidneys (60% metabolites, 40% parent drug). It has a half-life of about 5 to 6 hours. The drug half-life is prolonged and unpredictable in the elderly and in the presence of renal impairment, having poor correlation with creatinine clearance values. Its pharmacokinetics are relatively unchanged in the presence of mild to moderate hepatic dysfunction. Thirty milligrams of IV ketorolac provide similar analgesic results as 4 mg of IV morphine, but a similar dose via IM route is equivalent to 6 to 8 mg of IM morphine. When used with opioids for postoperative pain management, ketorolac reduces opioid requirements, lowering their potential side effects.

## Indications and Use

### Postoperative Pain

Currently, ketorolac is indicated for short-term (≤5 days) management of moderately severe pain in the postoperative setting. It may be given as a single or multiple dose on a regular or as-needed schedule up to a maximum of 5 days. Its frequently used dose profile is depicted in Table 80.1. For several decades, ketorolac 30 mg was the standard adult dose. This was likely due to the fact it was originally indicated for IM use and 30 mg was routinely administered. In review of the pharmacokinetics supplied by the manufacturer, similar peak plasma levels are obtained when a 15 mg IV dose is compared to a 30 mg IM dose. Ketorolac, like other nonsteroidal anti-inflammatory drugs, has a relative ceiling effect pharmacologically as an analgesic. While increasing dosage does not confer greater analgesia, adverse effects remain dose related. This pharmacologic ceiling is supported by recent studies. For example, a 2017 study by Motov and colleagues demonstrated similar analgesic efficacy at intravenous doses of 10, 15, and 30 mg in acute pain in an emergency room setting. In an additional study, Duttchen et al. of surgical spine patients showed that ketorolac 30 mg IV was not superior to 15 mg IV for postoperative pain management. IV injection is recommended to be given over at least 15 seconds, while the IM dose must be given slowly and deeply into the muscle. The time of onset of ketorolac is roughly 30 minutes. Peak effects are seen in 1 to 2 hours via either route, and clinical effects last for 4 to 6 hours. Mixing parenteral formulations with morphine, meperidine, promethazine, or hydroxyzine in the same syringe leads to precipitation and should be avoided.

**Table 80.1 ■ Recommended Dose of Ketorolac in Perioperative Setting**

| | Intramuscular (IM) | | Intravenous (IV) | | |
|---|---|---|---|---|---|
| | Single Dose Schedule | Multiple Dose Schedule | Single Dose Schedule | Multiple Dose Schedule | Oral (PO)[a] |
| Age 2–16 years | 1 mg/kg<br>Max = 30 mg | NR | 0.5 mg/kg<br>Max = 15 mg | NR | NR |
| Age >16 but <65 and BW ≥110 lb | 60 mg | 30 mg Q 6°<br>Max = 120 mg | 15–30 mg | 30 mg Q 6°<br>Max = 120 mg | 1st Dose = 2 tabs followed by 1 tab Q 4–6°<br>Max = 40 mg/d |
| Age ≥65<br>Or<br>BW <110 lb<br>Or<br>Renal Impairment | 30 mg | 15mg/kg Q 6°<br>Max = 60 mg | 7.5 mg to 15 mg | 15 mg Q 6°<br>Max = 60 mg | 1st Dose = 1 tab followed by 1 tab Q 4–6°<br>Max = 40 mg/d |

[a]Recommended ONLY as a continuation therapy of IM or IV ketorolac therapy.
BW, body weight; °, hours; lb, pounds; mg, milligrams; NR, not recommended; Q, every.

## Intravascular Regional Anesthesia (Bier Block)

A combination of lidocaine and ketorolac (20 mg) used for Bier block for hand and wrist surgery has been shown to result in significant postoperative analgesia and increased the interval to first request for postoperative analgesic request. A different study by Singh et al. used ketorolac 0.3 mg/kg with lidocaine for upper arm IVRA and ketorolac 0.15 mg/kg with good results. Interestingly, a report of two cases also described complete remission of complex regional pain syndrome in children who underwent Bier block with ketorolac/lidocaine.

## Periarticular Injection "Cocktail"

Local infiltrative analgesia (LIA) has been credited with significantly advancing the success and "tolerability" of total joint replacements, such as total knee replacement, when used as a component of a multimodal pain management strategy. A typical LIA cocktail is drawn up with ketorolac 30 mg, ropivacaine, epinephrine, and clonidine in saline to equal 100 mL. The LIA mixture is delivered with a 22G needle into the periosteum of the femur and tibia and the posterior capsule and arthrotomy.

**Table 80.2 ■ Common Concerns With Ketorolac Use**

| Relevant Side Effects | Contraindications |
|---|---|
| • Headache (17%) | • Active peptic ulcer disease |

| | |
|---|---|
| • Nausea (12%)<br>• Drowsiness or dizziness (6–7% each)<br>• Dyspepsia (12%)<br>• GI pain (13%)<br>• Peptic ulceration<br>• GI bleeding and/or perforation<br>• Platelet function inhibition<br>• Hypersensitivity reactions: range from bronchospasm to anaphylactic shock<br>• Acute renal failure<br>• Interstitial nephritis<br>• Nephrotic syndrome<br>• Fluid retention and edema (4%)<br>• Oliguria, elevated BUN, and creatinine<br>• Elevated liver enzymes | • Recent GI bleeding or perforation<br>• H/O peptic ulcer disease or GI bleeding<br>• Advanced renal impairment<br>• Renal failure risk due to volume depletion<br>• Suspected or confirmed cerebrovascular bleeding<br>• Hemorrhagic diathesis<br>• Incomplete hemostasis<br>• High risk of bleeding<br>• Prophylactic use before any major surgery<br>• Intraoperative use when hemostasis is critical<br>• H/O hypersensitivity reaction to ketorolac<br>• H/O allergic reaction to aspirin or other NSAIDs<br>• Concurrent use with aspirin or other NSAIDs<br>• Intrathecal or epidural use<br>• In labor and delivery |

BUN, blood urea nitrogen; GI, gastrointestinal; H/O, history of; NSAIDs, nonsteroidal anti-inflammatory drugs.

## Complications and Issues

Despite these desirable attributes, use of ketorolac comes with its own set of problems. The reported complications and ensuing discussions between clinicians have gone back and forth since ketorolac was introduced; hence the title of this chapter.

Its relevant side effects and absolute contraindications are described in Table 80.2. Prostaglandins play a positive role in the maintenance of platelet function and renal perfusion. The potent inhibitory effects of ketorolac on prostaglandin synthesis might jeopardize either of these vital phenomena. There is some evidence that ketorolac may impair bone growth, so some surgeons do not like it in spine fusions and fracture surgery. Ketorolac use should also be avoided in patients on therapeutic doses of anticoagulants, including prophylactic low-dose heparin therapy. It should also be avoided preoperatively, in any major surgical case, or when hemostasis is critical. It

should be kept in mind that ketorolac-induced increased risk of bleeding cannot be detected on routine testing, via platelet count, prothrombin time, or activated partial thromboplastin time. It should also be used with extreme caution, if at all, in patients with impaired renal function. Ketorolac may cause dose-dependent reduction in renal prostaglandin formation and may precipitate acute renal failure. This is more likely to occur in patients with impaired hepatic or renal functions, dehydration, heart failure, concomitant use of diuretics, angiotensin covering enzyme inhibition, or angiotensin receptor blocker therapy, and advanced age. It is, therefore, not surprising that our surgical colleagues get really nervous with ketorolac use.

Regardless of these intimidating concerns, ketorolac use has been shown to be relatively safe in innumerable studies. Despite the FDA's Black Box Warning against the use of NSAIDs following cardiac surgery, a 2014 study by Oliveri et al. reported that ketorolac appeared to be well-tolerated when used selectively after cardiac surgery and suggested that there was a need for further research regarding its perioperative administration after cardiac surgery (Note: we do **not** recommend you disregard the Black Box Warning at this time!). A recent meta-analysis showed that NSAIDs caused a clinically unimportant transient reduction in renal function in the early postoperative period in patients with normal preoperative renal function. The authors concluded that NSAIDs should not be withheld from adults with normal preoperative renal function because of concerns about postoperative renal impairment. Ketorolac has been shown t o effectively control postoperative pain after major abdominal, orthopedic, or gynecologic surgery, or after ambulatory laparoscopic procedures. Simultaneous use of ketorolac with opioids results in a 25% to 50% reduction in opioid requirement, resulting in reduction of side effects, more rapid return to normal gastrointestinal (GI) function, and a shorter in-hospital stay. However, many published case reports and case series have shown an increase in intra- and postoperative bleeding following tonsillectomy in children after ketorolac use. Previously, such findings were not reproduced in adults; however, a 2014 study by Chan and Parikh found the opposite and concluded, "Ketorolac can be used safely in children, but it is associated with a five-fold increased bleeding risk in adults. Ketorolac does increase bleeding time to some extent, but its actual contribution to surgical site bleeding is perhaps inconsequential. Besides, these risks can be reduced to minimal by adhering to its strict treatment guidelines.

It is imperative for anesthesiologists to be aware of issues related to ketorolac prior to its use. Thorough knowledge would help us enhance the pleasant nature of the "Toradol conversation" with our surgical associates. No textbook can teach us communication skills, which would certainly come in handy during these intricate dialogues. Surgeons do have the right to know the anesthetic management and our plans

for postoperative pain control. A formal discussion would help them understand the benefits of ketorolac and would also help their patients in the long run.

## TAKE HOME POINTS

- Ketorolac tromethamine is a nonselective NSAID available in both parenteral and oral formulations for the management of moderately severe pain in the postoperative setting for ≤5 days.
- Ketorolac is also used as an adjunct medication in intravascular regional anesthesia (Bier block) and in LIA cocktails for joint surgery.
- Administering 30 mg of IV ketorolac has the same equivalent analgesic effect as 4 mg of IV morphine, with much lower incidence of nausea.
- The typical standard adult intravenous dose is now 15 mg or 7.5 mg to 10 mg for older patients.
- Ketorolac is contraindicated in patients with a history of peptic ulcer disease, bleeding problems, and advanced renal impairment, or in patients at risk for renal failure due to volume depletion, prior to major surgery, in the presence of uncertain hemostasis.
- Ketorolac has been shown to be a safe and effective analgesic agent in the postoperative setting.
- A mutual agreement between the anesthesiologist and the surgeon prior to the use of ketorolac would result in a more cordial atmosphere and better patient outcomes. One thing that has changed for the better in operating room culture in recent years is that OR staff are now routinely doing timeouts or huddles at the beginning of cases. This is a good time to discuss the use of ketorolac!

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# Special Topic I: Do Patient With Congenital Insensitivity to Pain Need Anesthetics and Postoperative Opioids?

Katarina Bojanić, MD PhD, Toby N. Weingarten, MD, and Juraj Sprung, MD PhD

## Hereditary Sensory and Autonomic Neuropathy

Congenital hyposensitivity to pain, hereditary sensory and autonomic neuropathy (HSAN), is a group of rare genetic disorders characterized by varying degrees of sensory loss, including nociceptive hyposensitivity, loss of other types of sensation, and various degrees of autonomic dysfunction. Sensory loss, especially the loss of pain sensation, is associated with self-mutilation that may require frequent surgery (Fig. 81.1). Little is known regarding whether or how much these patients require anesthesia for surgery or opioids postoperatively. Furthermore, because of various degrees of autonomic dysfunction, these patients may be at increased risk of perioperative anesthetic complications.

## Classification of Congenital Hyposensitivity to Pain

Congenital hyposensitivity to pain disorders were categorized by Dyck et al. into five different types of HSANs (I to V). Different expressions of sensory loss are possible within each HSAN category, and some patients may have variable pain sensation. The types of HSAN are distinguished by the mode of inheritance, clinical features, degree of autonomic nervous system abnormalities, loss or degeneration of sensory fibers, and increasingly specific molecular genetic abnormalities.

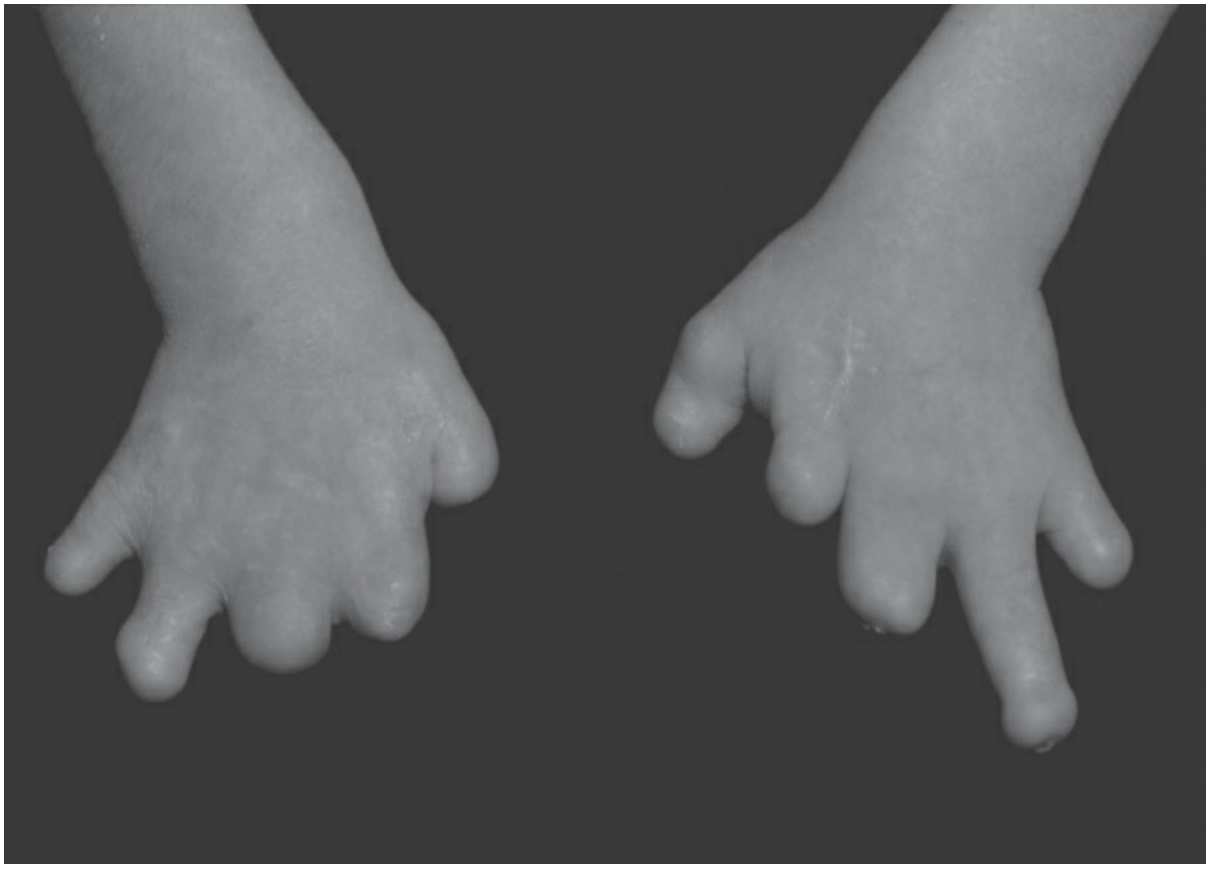

**Figure 81.1.** The hands of a 12-year-old boy with hereditary sensory and autonomic neuropathy (HSAN) II showing acromutilation. This type of self-mutilation may be found in all types of recessively inherited HSANs and is attributed to loss of pain sensation, neglect of injury, excessive surgery, and indifferent personality. (Reprinted with permission from Weingarten TN, Sprung J, Ackerman JD, et al. Anesthesia and patients with congenital hyposensitivity to pain. Anesthesiology. 2006;105(2):338–345. Copyright © 2006 American Society of Anesthesiologists, Inc.)

- **HSAN I** is the only autosomal dominant disorder. It is characterized by onset later in life and a sensory deficit that is more pronounced in the legs than in the hands. In HSAN I, sensory deficits overshadow autonomic dysfunction.
- **HSAN II** patients tend to have pain hyposensitivity of the upper and lower limbs. Many have defective tactile sensation, whereas a minority may have areas of normal trunk sensation. Relevant autonomic dysfunction may include episodic hyperthermia and swallowing deficiencies.
- **HSAN III**, also known as Riley–Day syndrome or familial dysautonomia, has a higher prevalence in Ashkenazi Jews. These patients typically present in infancy with a profound dysautonomia (poor feeding with repeated vomiting, failure to thrive, and temperature and vasomotor dysregulation associated with hypertension or hypotension), recurrent pulmonary infections, diminished peripheral pain and temperature sensation, and absence of vibratory perception.
- **HSAN IV**, also known as congenital insensitivity to pain with anhidrosis, is characterized by hyposensitivity to superficial and deep visceral pain, mild to

moderate mental retardation, and recurrent episodes of hyperpyrexia due to absence of sweating (no innervation of sweat glands).

- **HSAN V**, also known as congenital insensitivity to pain without anhidrosis, resembles HSAN IV but is associated with a selective absence of small sensory myelinated fibers (Aδ fibers), which are important for sensing the sharp, well-localized, and prickling sensations of pain. These patients typically respond to tactile, vibratory, and thermal stimuli.

## Anesthesia and Hereditary Sensory and Autonomic Neuropathy Disorders

No consensus exists regarding the intraoperative analgesic needs of HSAN patients. Some patients with HSAN have tactile hyperesthesia, and some may have partially preserved pain sensation; therefore, most reports have described the use of volatile anesthetics in standard concentrations. In addition, anesthetics are necessary to ensure cooperation and immobility during surgery for pediatric patients, especially for those with mental retardation. The optimal dose of anesthetics for patients with HSAN has yet to be determined. At present, inhalational anesthetics should be titrated in accordance with the patient's hemodynamic response. A case reported by Layman showed that, in a 30-year-old man with congenital insensitivity to pain, bilateral lower-extremity amputation could be performed by using only heavy sedation, without opioids or general anesthesia.

Most reports have documented minimal or no use of opioids postoperatively in patients with HSAN IV. When opioids were used perioperatively, no reasoning for their use was offered. The use of opioids in these patients may have followed the anesthesiologists' daily practice of administering opioids with every anesthetic. This "automatism" may occur because HSAN is rarely encountered by anesthesiologists, and because scarce information and no recommendations exist regarding opioid requirements for these patients. Furthermore, some patients with HSAN may have partially preserved nociception, and others may have preserved mechanoreceptor, cooling, and warming sensations; therefore, they may sense some aspects of intense surgical stimulation.

Despite decreased pain perception in patients with HSANs, anesthetic administration for these patients has generally been similar to that for patients with normal pain perception. Postoperatively, these patients have minimal or no pain, and most did not require opioid medications.

## Perioperative Management of Body Temperature

Besides hyposensitivity to pain, patients with HSAN have various degrees of autonomic

dysfunction that may affect the course of anesthesia. An important element of anesthesia is prevention of autonomic reflexes. Because patients with HSAN IV have anhidrosis, management of temperature homeostasis in daily life may be difficult. One study indicated that almost 20% of these patients died of hyperpyrexia during the first 3 years of life. Thus, perioperative thermoregulation is a concern, and continuous temperature monitoring is of great importance in these patients. Only one report has documented intraoperative hyperthermia in a patient with hyposensitivity to pain; in general, normothermia can be easily maintained with alterations of environmental temperature. Atropine inhibits the activity of the sweat glands and, in healthy children, may cause hyperthermia. However, because children with HSAN IV lack innervation of sweat glands, the use of atropine should not be associated with hyperthermia. Of note, malignant hyperthermia is not associated with HSAN IV; the genetic mechanisms for precipitating hyperpyrexia in malignant hyperthermia and HSAN IV are fundamentally different. All triggering agents associated with malignant hyperthermia (succinylcholine, halogenated agents, and others) have been used without any complications in HSAN patients.

## Perioperative Prevention of Aspiration

Patients with congenital insensitivity to pain should always be considered as having a "full stomach," regardless of the duration of their NPO status, due to their coexisting autonomic nervous system abnormalities. Anesthesia in patients with HSAN may be complicated by regurgitation, and subsequent aspiration. This especially applies to patients anesthetized with unprotected airway (laryngeal mask airway). Therefore, rapid-sequence induction with an endotracheal tube should be utilized for the anesthetic management in every patient with HSAN.

### TAKE HOME POINTS

- Knowledge regarding the safety of anesthesia in patients with HSAN II, IV, and V is scarce. To date, anesthesia has not been associated with any major adverse events in patients with HSAN disorders.
- Although patients with profound congenital insensitivity to pain may undergo major surgery without general anesthesia, most reports indicate that these patients received standard doses of anesthesia for operations.
- Factors other than analgesia, such as immobilization, prevention of autonomic reflexes, anxiolysis, and sedation, are equally important aspects of these patients' anesthetic management.
- Generally, patients with HSAN II, IV, and V do not need opioids postoperatively,

even after major operations.

- Generally, precaution regarding perioperative aspiration need to be considered.

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# Special Topic II: Can Your Patients Eat Their Way Out of Chronic Pain? Some Common Sense Advice

Ashley R. Valentine, MD PhD

When teaching in the community about healthy eating, my PhD advisor used to say, "Everything in moderation, except colorful vegetables." Her adage brings to mind several commonly-accepted truths about nutrition: (1) human diets are widely variable, (2) eating too much or too little of any one thing is a health risk, and (3) the diets of Americans are typically lacking in foods considered the most nutritious, especially colorful vegetables. In fact, the proinflammatory effects of the Western diet (loosely defined and characterized by excessive consumption of saturated fats; omega-6 fatty acids; red and processed meats; sodium; processed carbohydrates; and lacking in vegetables, legumes, fish, and whole grains) are well established. This dietary pattern is known to contribute to the high prevalence of hypertension, hyperlipidemia, diabetes, and obesity in the United States. But what about a link to chronic pain?

The relationship between diet composition and chronic pain in the adult population is not well characterized. This is likely due to the complexity of both fields of research. Investigating isolated nutrient effects on pain ignores the importance of nutrient–nutrient interactions and whole-diet effects. On the other hand, global dietary changes made in the context of a study are often not sustained after the study ends. Also, these studies many not identify the most efficacious components of the diet. Chronic pain conditions are numerous and vary in etiology, lending to research focused on specific conditions and diet, with results that are not generalizable. Obesity and weight-loss are confounding factors that might be difficult to tease out in statistical analyses. Nonetheless, given the known relationship between inflammation and chronic pain disorders, a plausible biologic explanation exists that consumption of a proinflammatory diet could increase susceptibility to and maintenance of chronic pain states. Indeed, a recent study in mice fed ad lib Total Western Diet (formulated to represent the median diet reported in the National Health and Nutrition Examination Survey, 2007–2008) showed similar body weights but increased inflammatory

cytokines, duration of allodynia, and duration of hyperalgesia in the setting of inflammatory chronic pain compared with mice consuming standard chow.

Perhaps consumption of anti-inflammatory and/or reduction of proinflammatory foods in the diet can offer analgesic benefit for patients with pain. For example, gluten-free, ketogenic, Mediterranean, vegan, and vegetarian dietary patterns typically provide higher amounts of anti-inflammatory foods compared to a typical Western diet. Studies frequently show reductions in circulating inflammatory cytokines in animals fed similar diets. However, effects of these dietary patterns on pain and painful conditions in humans are mixed. Furthermore, the study designs, pain outcomes, and composition of these diets in studies are so variable that few meta-analyses have been performed. For example, vegetarian and vegan diets have been studied in rheumatoid arthritis, and in some cases have reduced pain and joint swelling. A Cochrane review was unable to perform a meta-analysis of these studies due to data heterogeneity. The review concluded that the available studies of dietary manipulation to treat pain in this population suffered from at least moderate bias, treatment effects remained unclear, and the high dropout rates in treatment groups were concerning.

What should we advise our chronic pain patients about their dietary habits? Thinking small and working up, certainly micronutrient deficiencies and excesses should be considered, evaluated for, and addressed if present. Most micronutrient deficiencies are rare in the United States, and risk goes down as diet quality, lifestyle quality, and food security increases. Typically, micronutrient deficiencies will not present as an isolated pain syndrome. However, consider deficiencies in vitamins such as cobalamin (potentially painful numbness/tingling of extremities), thiamine (muscle cramps, lower-extremity paresthesias, burning pain, abdominal pain), magnesium (muscle cramping, myalgias), vitamin D (bone pain, myalgias), and iron (restless legs, sore tongue).

If recommending dietary supplements to patients, remember that in the United States supplements are regulated as “foods” by the Food and Drug Administration (FDA). The supplement industry is not subject to the same rigorous standards as drug manufacturing. From their website, the “FDA is not authorized to review dietary supplement products for safety and effectiveness before they are marketed.” Supplement manufacturers are required to follow FDA rules on labeling and current Good Manufacturing Practice, but are not required to undergo independent verification of their claims or production practices. In many instances, such as independent consumer testing lab analyses and even personal experience analyzing supplements as a graduate student, supplements did not contain what was claimed on their label. In addition, contamination with potential allergens such as wheat, gluten, and peanuts is common. It may add a degree of safety to recommend supplements that have been certified by a third party such as the United States Pharmacopeial Convention (USP), the National Sanitation Foundation (NSF), the

Natural Products Association (NPA), and the International Fish Oil Standards Program (IFOS). However, be wary of false claims. Product labeling with the letters "USP" is not the same as a product containing the official USP verified seal, for example.

In contrast to deficiencies, excessive micronutrient intake can also cause generalized pain. Hypervitaminosis A and D, as well as excessive calcium can cause muscle, joint, and/or bone pain and may result from overconsumption of supplements and certain foods, or medication–supplement interactions.

For a given pain diagnosis, it may be beneficial to try some of the dietary alterations or supplements suggested in published research. Unfortunately, many of these studies have shown mixed results, are retrospective, are not easily generalizable, do not give specific details of the dietary intervention, require intensive dietician/nutritionist support, or are not sustainable. Fortunately, very few of the suggested dietary changes could result in harm. Examples of tailored dietary interventions include:

- Chronic daily headache—Try increasing omega-3 while decreasing omega-6 fatty acids
- Fibromyalgia—Consider a trial of gluten-free, vegetarian, or vegan diet
- Migraine headache—Avoid dietary triggers; consider low-fat or vegan diet; trial a ketogenic diet prescribed by a dietician; try feverfew for prevention
- Nonspecific headache—Avoid aspartame, monosodium glutamate, and high caffeine intake
- Osteoarthritis—Consider a calorie reduction diet for weight loss in conjunction with an exercise plan in overweight/obese patients
- Rheumatoid arthritis—Consider gluten-free, vegetarian, or vegan diets

For many of the above conditions, patients may suspect that a dietary component is contributing to their pain or may want to identify triggers (for migraines, for example.) An elimination diet guided by a nutritionist or dietician is an intensive, but potentially highly effective, method to identify triggers for the motivated patient.

Finally, and perhaps most importantly, a global improvement in diet quality is likely beneficial to all chronic pain patients, even if specific evidence is lacking in terms of pain outcomes. Patients can be counseled that decreasing inflammation in the body caused by unhealthy eating could, theoretically, offer improvement in overall pain and energy. Furthermore, sustaining healthy eating is known to improve blood pressure, decrease risk of several chronic diseases, and decrease the risk of cardiovascular death. While the primary goal is healthy eating habits, improving dietary quality often has the beneficial side effect of weight loss, without calorie counting, in obese and overweight patients.

Patients can choose to follow any one of several healthy eating patterns (e.g., Mediterranean, Dietary Approaches to Stop Hypertension, or MyPlate) or create their

own. There should be a focus on reducing processed foods/grains, saturated fats, omega-6 fatty acids, and processed and red meats, while increasing green leafy and colorful vegetables, nuts, highly pigmented fruits like berries, whole grains, fatty fish, legumes, tree nuts, and olive oil. There are numerous free, high-quality online resources available to help. It should be emphasized to patients that in most studies the changes in eating habits were maintained for weeks to months before benefits were realized. Patients should be reminded that the goal is a life-long habit of healthy eating. Although the transition may be challenging, once established, these eating patterns can be easy to maintain. Patients may embark on dietary change independently, but it is probably best to have them work with a dietician or nutritionist for initial dietary assessment, education, planning, and to make sure no new micro- or macronutrient deficiencies develop.

Some patients will ask for specific supplements that are considered "anti-inflammatory." Some supplements may decrease inflammatory cytokines as shown in animal models and some human studies. These include omega-3 fatty acids) (e.g., docosahexaenoic [DHA] and eicosapentaenoic acids [EPA]), grape seed extract, ginseng, and green tea extracts. Whole foods that are beneficial include salmon, halibut, tuna, and trout (DHA and EPA); dark green vegetables (fiber, phytochemicals); orange, yellow, or red vegetables (carotenoids); onion, garlic, ginger, and turmeric; green tea; and dark chocolate and red wine (in modest amounts, of course).

It all sounds so delicious and healthy, so why are dietary changes so difficult to make? We know that food, or perhaps the act of eating itself, can be comforting and temporarily distract from or relieve pain. When we reach for "comfort foods" we rarely go looking for a carrot to crunch, but rather crave a high fat, sugary, and/or salty snack. There is a clear link between eating to regulate emotions and an emerging link with pain, with some individuals eating more and others restricting intake. In a qualitative study of eating behaviors in obese patients with chronic pain, focus groups revealed themes of pain-triggering hedonic hunger, eating to soothe pain, and a preference for foods higher in sugar, fat, and calories when eating in response to pain. Depression or low mood also played a role in dietary preferences and desire to eat. College students with pain had unhealthy eating behaviors compared with pain-free peers. Greater pain catastrophizing was related to unhealthy or emotional eating behaviors. Helping patients manage emotional responses to pain through counseling may also improve eating habits. A final hindering factor is cost. High-quality, nutrient-rich dietary patterns can be more costly (or take more effort to plan and shop for) than calorie-rich ones. This is a barrier for low-income patients.

Best practices to get patients to improve their dietary habits over time are not clear, but there are some data on techniques that may help. A recent meta-regression examined

behavior change techniques for diet and physical activity in obese subjects. The two techniques that most strongly predicted both short- and long-term intervention effects were setting a goal for behavior change and monitoring the new behavior. A separate evaluation of behavior change techniques for diet and physical activity in Type 2 diabetics suggested structuring interventions such that credible experts deliver the key components of the intervention (e.g., a dietician to discuss nutrition). Including these elements in the clinical plan may help chronic pain patients make beneficial dietary changes. Hopefully, with proper support, patients can integrate healthy eating into a healthier lifestyle, with the end-result of reduced pain.

## TAKE HOME POINTS

- The Western (American) diet may create an internal inflammatory milieu that promotes chronic pain.
- A dietary pattern with greater emphasis on anti-inflammatory foods might decrease the risk of chronic pain and chronic pain severity. Published data to support this theory are lacking.
- A healthy eating pattern can be tailored to individual patients and provides a multitude of long-term health benefits, even when weight loss is not the goal.
- Dietary supplements are not subject to the same rigorous quality standards as drugs. Supplement producers are required to be honest in labeling, but consumer groups have revealed gross inaccuracies in content. Consider recommending supplements with legitimate third-party certification.
- Behavior change is difficult, especially for patients whose eating behaviors may play a role in how they manage their chronic pain. A multidisciplinary team including a pain psychologist and dietician/nutritionist may be beneficial.

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# Attacking Acute Perioperative Hypertension—The Cleveland Group Shares Their Battle Plan

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A 46-year-old morbidly obese male presents for elective massive ventral herniorrhaphy with abdominal wall reconstruction. His past medical history is also significant for mild renal insufficiency and scattered cutaneous fungal infections. Vital signs in the preoperative holding area are as follows: heart rate 82 beats per minute and regular, respirations 19 breaths per minute, blood pressure (BP) 187/112 mm Hg, $SpO_2$ 96% (room air). The patient comments that he was confused about what to take and what not to take as far as antihypertensives, so he did not take any today, or yesterday. Review of his medication list reveals that he is on amlodipine, metoprolol, and lisinopril. Your anesthesia resident suggests using a noninvasive oscillatory/near infra-red finger cuff for BP monitoring rather than an indwelling arterial catheter as he is not expected to go to the intensive care unit following surgery. However, your resident is not certain what BP range will be appropriate for this patient. How will you proceed to select a safe and appropriate BP range and what first-line antihypertensive therapy will you select?

## Pharmacologic Acute Hypertension Management Tools —The Sharp End of the Stick

Because you are at a certain tertiary care hospital (in the state of Ohio), you okay the use of a noninvasive oscillatory/near infra-red finger cuff BP monitoring system. You discuss with your resident, however, that in many places (maybe Pittsburgh or maybe Portland?) this patient would get an arterial line and go to the ICU post-op, which would be entirely appropriate. But you also discuss with your colleague that wherever you go, there you are. And….in this case, you're in Cleveland and your particular practice group is comfortable using this device to provide beat-to-beat BP assessment and advanced hemodynamic monitoring parameters including cardiac index and stroke volume index. This system will also guide optimal fluid management during this big case that is expected to have some significant fluid shifts. Maintaining a cardiac index

of greater than or equal to 3.0 L/min/$m^2$ (normal range 2.2 to 4.0), or even better a stroke volume index of greater than or equal to 35 mL/$m^2$/beat (normal range 33 to 47) will help insure adequate oxygen delivery to all vital organs. However, adequate blood flow, or cardiac index does not guarantee perfusion as there must also be appropriate perfusion pressure. In this case, at our institution (again, we note:not everywhere but here in Cleveland, yes) we would use a cerebral oximeter to ensure BP is high enough to maintain cerebral oxygen balance in the setting of a good cardiac index (and so far we do not need to worry about our vignette patient having too low a BP). Remember to always get awake room air baselines with the cerebral oximeter and that a desaturation of 20% or more below the established baselines is considered a significant desaturation and your goal is to avoid getting anywhere near such a desaturation level. **IMPORTANT:** Also note that when the cerebral oxygen saturation goes up and down in concert with lower and higher BP that the patient is below the lower limit of cerebral autoregulation and flow is now pressure passive, so it is your job to increase perfusion pressure and restore the cerebral saturations to the baselines. Once you have determined an appropriate BP range for our patient, it is now time to "choose your weapon" if the patient continues to be hypertensive.

## The Downers (aka Vasodilators)—The Ideal Drug

Acute hypertension is extremely common in the perioperative period, even among patients without the diagnosis of chronic hypertension, for a multitude of reasons. And once you have established that observed hypertension is not related to anxiety, pain, hypercarbia, monitor infidelity, or light anesthesia, then it is time to administer an intravenous (IV) antihypertensive agent. Before selecting a drug always keep in mind that, with few exceptions, perioperative acute hypertension is ultimately related to sympathetic discharge that results in increased vasomotor tone as well as increased inotropy and chronotropy—although in many patients on beta-blocker therapy one may only see the increase in systemic vascular resistance. When BP is considered in its most simple form it is defined by the following equation:

$$\text{Mean Arterial Pressure (MAP)} = \text{cardiac output (CO)} \times \text{systemic vascular resistance (SVR)}$$

Of the two variables that govern MAP, one is easy to titrate (i.e., SVR) and one is not (i.e., CO). This said, it makes a lot more sense to choose a selective arterial vasodilator to effectively treat acute perioperative hypertension and comparative clinical trial data fully confirm this concept.

An ideal drug would be arterial-selective, have a short half-life (i.e., be easy to back out of when you no longer need it), possess few side effects, lack tachyphylaxis, not be

greatly dependent on organ function for its metabolism (i.e., comes in handy in a patient with shoddy kidneys and/or liver), be available in IV form, have minimal interactions with other drugs, and be economical. It is not always about "show me the money," but the money certainly gets a seat at the table!

## Calcium Channel Blockers—But Not Just Any Calcium Channel Blocker

This is because not all calcium channel blockers are the same, not even close to be created equal. We teach the calcium channel blockers as two distinct classes of drugs that have different structures and do different things. So, with that in mind, calcium channel blockers are used to "treat" two things—SVR and supraventricular tachycardia (SVT). The SVR-treating calcium channel blockers are dihydropyridine drugs and act on smooth muscle. The SVT-treating calcium channel blockers are phenylalkylamine drugs such as verapamil—they work minimally on smooth muscle but also have strong AV nodal effects. We discuss all of these below, starting with the SVR-smooth muscle dihydropyridines.

## Calcium Channel Blockers—Dihydropyridine L-type

We feel that in our practice setting, the class of drug at the top of the list for the treatment of acute perioperative hypertension is the **dihydropyridines.** These drugs work by selectively blocking the L-type calcium channel in arterial smooth muscle (i.e., only in pulmonary and systemic arteries). They are based on the pyridine molecule. You will remember learning in medical school about the earlier and most widely recognized drugs in the dihydropyridine class—amlodipine, felodipine, nifedipine, and nicardipine. The arterial-specific nature of these agents results in a decreased systemic and pulmonary vascular resistance and an increase in cardiac index; however, in contrast to other classes of calcium channel blockers they have no negative inotropic effects at clinical doses.

Two forms of the dihydropyridines are available. The first is clevidipine, a third-generation dihydropyridine, which is ultrashort acting with a half-life of approximately 60 seconds per the manufacturer package insert because it is metabolized by nonspecific tissue and plasma esterases. Clevidipine is dosed in a nonweight-dependent manner and is prepared in the same soy-lecithin emulsion as is propofol, because like propofol it is not soluble in aqueous solution. With its ultrashort half-life, bolus use of clevidipine is not necessary if an infusion is started and titrated at an appropriate rate. Note that several perioperative studies have demonstrated that the average time to achieve target blood pressure with clevidipine is approximately 5 to 6 minutes; bolus use of clevidipine is considered off label but has been reported. As with all vasoactives, it is

best to administer the drug in a dedicated IV to avoid inadvertent bolusing; however, it is compatible with mostly all crystalloidal and albumin-based colloidal solutions. Note that as with infusions of any vasoactive drug, make certain that it is as proximal to the patient as possible relative to the IV tubing to avoid a long lag time in seeing an initial effect.

Clevidipine is started at a rate of 1 mg/hr to 2 mg/hr and then the dose is doubled every 90 seconds until one gets closer to the desired BP target at which point the dose timing intervals can be spread out to 3 to 5 minutes and be reduced to 1 mg/hr to 2 mg/hr increments to attain precise BP control in the target range; the average dose in perioperative patients is in the 6 mg/hr to 8 mg/hr neighborhood. Further, in perioperative studies the average time achieving target BP control is about 5 minutes. It is unusual to have to exceed doses of 14 mg/hr with clevidipine, and in our practice rarely does doing so result in better BP control; so consider adding a second agent like IV esmolol if dosage of clevidipine exceeds 14 mg/hr and BP target has not been achieved. The clinical effect of clevidipine does not directly mirror its half-life because although 90% of the active drug is removed from the circulation within 1 minute of drug cessation, the L-type calcium channels take longer to reset producing a graded return in vascular tone that is mostly recovered in about 5 to 8 minutes. There is no absolute need per se to have an arterial line when administering clevidipine, due to its very predictable effects, although certainly an arterial line is commonly and often appropriately placed in patients with significant perioperative hypertension.

Clevidipine metabolism is not dependent on renal or hepatic function. Similar to propofol, clevidipine cannot be given to patients allergic to soy or egg lecithin, must be handled with aseptic technique, and has no active metabolites. Clevidipine has a cost per vial similar to IV nicardipine, a longer-acting dihydropyridine (half-life 12 to 14 hours) that is hepatically metabolized. Since nicardipine has the same pharmacodynamic mechanism as clevidipine and a long half-life, it is more commonly used perioperatively in neurosurgical patients who tend to have the prolonged need for IV antihypertensive therapy related to brain edema and its associated physiologic reflexes. Use of nicardipine without a bolus may result in a longer time to achieve target BP and although bolus use is off label it is a common practice among perioperative clinicians. Nicardipine bolus dosing in the range of 0.2 mg to 1.0 mg can result in safe decreases in BP; an infusion dose of anywhere from 1 mg/hr to 15 mg/hr (3 mg/hr is a common dose) may be needed to achieve target BP without a bolus. Rapid titration protocols of nicardipine are available from the manufacturer. N.B.: From direct experience with development studies of clevidipine and longstanding clinical use of nicardipine, both IV dihydropyridines appear to have a 5% to 8% “incomplete responder” rate which means that a second IV antihypertensive may be needed if target BP control is not reached with

manufacturer-recommended dosing. Finally, a large comparative study has definitively established that perioperative use of IV dihydropyridines is superior to nitrovasodilators in terms of achieving and maintaining target BP control.

## Nitrovasodilators (aka Nitric Oxide Donors)

Nitrovasodilators remain popular and widely available. They are marginally effective options compared to the dihydropyridines for treating acute perioperative hypertension, but may be what is available. This drug class includes both IV sodium nitroprusside (SNP) and nitroglycerin. They both work by ultimately donating a nitric oxide molecule to effect vasodilation. They are both prodrugs which must be activated by differing mechanisms, which explains why they have different maximal dilation. Nitroprusside has a short half-life (approximately 2 to 3 minutes) and depends on both normal hepatic and renal function for its complete metabolism; it works on all vascular smooth muscles inclusive of both systemic and pulmonary arterial and venous vessels. Given that it affects both preload and afterload, it is prone to producing unexpected overshoots during BP management (especially if your patient is at all volume-depleted) that result in the need for several more dose titrations and rescue vasoconstrictor bolusing to achieve and maintain target BP. This agent is also well known for inducing systemic hypoxia by opening up intrapulmonary shunts in the microvascular tissue beds. In addition, each nitroprusside molecule must release five cyanide molecules into the circulation to liberate one nitric oxide molecule which can result in organ toxicity in patients with limited renal and/or hepatic function.

Nitroprusside is commonly used as an IV infusion but is also used in bolus form which is considered off-label use. Nitroprusside is potentially highly toxic and severely noneconomical with previous acquisition costs spiking in the neighborhood of $1,000/vial, although that has recently decreased somewhat. Indeed, there appears to be no good reason to us to continue the perioperative use of nitroprusside, if you have an alternative. If you do not have an alternative to SNP, then pay rigorous attention to the cumulative effects and the possibility of toxicity, which is dependent on the dose, duration of the infusion, and the ability to eliminate the drug (renal and hepatic). And make sure you have control of the SNP dose and dilution, do not give an inadvertent bolus when setting up an infusion, and are prepared pharmacologically to correct overshoots, sometimes known in the old days as “riding the rollercoaster.” But if you do have the availability of a dihydropyridine, we advise that it is time to move on from perioperative nitroprusside use … seriously.

**But, wait, one final note about nitroprusside**. As this chapter was in preparation, one of the editors sent us an email about her prior use of low-dose SNP for acute but brief hypertension at the end of vascular cases, such as carotid endarterectomies. A

syringe of SNP in the dose of 10 μg/mL on the cart for every case where a significant blood pressure spike was reasonably anticipated did the trick when given 1 mL at a time, for hundreds, if not thousands, of cases. So what about that, how do you replace that? Our reply to that is as follows: Yes, if you are older than 30 years old you either did this yourself or remember somebody telling you about it. Lots of folks used SNP like that…until the price was raised from $7.80/vial to $1,000/vial. The price of SNP is now somewhat lower, but still extremely high. An interesting exercise is to call your hospital pharmacy and ask what the Average Wholesale Price (AWP) is for SNP and then compare it to other drugs you are considering. Clevidipine and nicardipine can also be bolused and both go for approximately $65 a vial/bag. One of us (EA) did the only bolus study of clevidipine with a collaborator at Penn several years ago. Clevidipine does not really need a bolus because its half-life is about 20 seconds in reality (it says about 1 minute in the package insert but it hits steady state in 90 seconds). SNP can only be effectively metabolized in patients with a good set of kidneys and a good liver. In our view, it is a drug that is pharmacologically deleterious and ridiculously expensive. That said, the manufacturer has started to lower the cost of the drug in some markets across the United States to around $300/vial for SNP, which we think is still ridiculous. As we discuss above, the effects of SNP are unpredictable because it hits arterial and venous tone and thus can reduce cardiac preload at the same time as afterload which results in frequent overshoots, especially in patients with stiff ventricles. SNP is not predictable and in head-to-head trials against clevidipine and nicardipine it got buried, plain and simple, because of its unpredictable effects. We admit that it is always good at lowering BP but the decreases are just too unpredictable.

And, yes, we do use a syringe of clevidipine at our institution in the cardiac rooms, but you are not really saving much time as it kicks in about 45 seconds as a bolus and the same amount of time for a drip. Clevidipine 1 mL, 500 μg/mL, drops SBP average of 38 mm Hg and clevidipine, 250 μg in a bolus dose, will drop the blood pressure an average of 18 mm Hg. Again, if you start the drip at 4 mg/hr or 6 mg/hr and turn it off when you start to see an effect, that will pretty much have the same effect as the bolus.

Nitroglycerin also works by donating a nitric oxide molecule to effect vasodilation. Nitroglycerin works primarily by vasodilating venous smooth muscle and does have some modest effects on arterial smooth muscle. While nitroglycerin is an effective myocardial anti-ischemic drug, it fares poorly as an antihypertensive in head-to-head studies with the dihydropyridines. It effectively lowers BP by reducing cardiac preload, which in many cases leads to difficult-to-titrate drops in arterial BP, especially in patients with noncompliant ventricles who are “preload dependent” as if any one of us does not depend on preload. Using nitroglycerin to control BP is a little like trying to maneuver a sports car through S-curves by tying a rope to each of the front tires and

pulling with all your might; it is much easier to use the steering wheel mechanism, so use an IV dihydropyridine. Try it, you will like it.

## Beta- and Alpha-Antagonists

Another popular class of BP control agents is the beta-antagonists and mixed alpha-/beta-antagonists. These drugs have different effects depending on whether they are specific for beta-, alpha-, or mixed alpha-/beta-antagonism. While beta-blockers are popular choices for outpatient treatment of chronic hypertension, they may be difficult to use for titrating perioperative BP into a specific target range without overshoots or unwanted bradycardia. REMEMBER: MAP = CO × SVR and CO is not an easily titratable way to control BP compared to SVR. As one may anticipate, their primary mechanism of action is to reduce both the chronotropic and inotropic states of the heart which will reduce CO and ultimately BP.

There is a secondary antihypertensive effect that includes beta-1 blockade on the juxtaglomerular apparatus of the kidney which decreases rennin, angiotensin, and aldosterone. Beta-1 specific antagonists have variable half-lives and include metoprolol (half-life 3 to 4 hours), atenolol (half-life 6 to 7 hours), and esmolol (half-life 9 minutes), all of which have been used perioperatively. The longer half-lives generally exclude metoprolol and atenolol use as preferred choices in the perioperative period. However, in patients with an incomplete response to the dihydropyridines who have sufficient reserve in terms of heart rate, esmolol can be excellent as a supplemental antihypertensive agent, that is, allows one to maintain that tight control of BP range that makes the dihydropyridines so useful. Esmolol infusions are commonly run at doses of 50 µg/kg/min to 250 µg/kg/min, with or without a loading dose of 100 µg/kg to 600 µg/kg over 2 minutes. But consider that loading doses may not be needed if esmolol is used in concert with dihydropyridines. In patients with persistent perioperative hypertension that have sufficient heart rate reserve, the use of IV metoprolol and atenolol can be effective. Both metoprolol and atenolol are titrated in slowly at 1 mg to 2 mg increments with ideally at least 5 minutes in between doses so as not to overshoot or get into an unwanted bradycardia situation.

The most commonly used mixed IV alpha-/beta-antagonist in the perioperative period is labetalol (half-life 4 to 6 hours) which preferentially blocks the beta receptors over the alpha-receptors at a ratio of 7:1. Because labetalol is primarily a beta-blocker its use can be limited perioperatively by bradycardia or its longer half-life. For patients with persistent perioperative hypertension, whom we are trying to wean from infusions so they can get out of the postanesthesia care unit, it can be a great choice. Labetalol is usually given in boluses of 5 mg to 10 mg at a time with 5-minute intervals between dosing to avoid overshoots and bradycardia.

## Alpha-2 Agonist

Clonidine, a centrally acting alpha-2 receptor agonist that decreases sympathetic outflow from the central nervous system, is in most cases a poor choice of intravenous perioperative antihypertensive agent (half-life 5 to 25 hours). We have found that the use of IV clonidine in doses ranging from 0.15 mg to 0.5 mg can result in profound hypotension and bradycardia, especially in patients being treated with diuretics. Clonidine may have a role in the perioperative period among patients that are being treated with oral clonidine as outpatients for their hypertension. It may also have desired adjunctive effects when administered as a low-dose patch and have efficacy in other areas besides hemodynamic control. And patients who skipped their scheduled oral dose of clonidine can present with rapid increases in BP that should respond well to IV clonidine in small divided doses over at least 10-minute intervals. But we recommend you to avoid significant doses of IV clonidine use for the primary control of acute intraoperative hypertension like you would avoid an angry badger.

## Oddball IV Antihypertensives

As far as remaining oddball IV perioperative antihypertensives, we are scraping the bottom of the barrel here but will have to mention hydralazine. Nobody is willing to commit to assigning a half-life to this drug (but rest assured it is in the several hours range) because it appears to depend on how much protein binding with this drug occurs in the blood—you can chalk this up to one of the reasons we suggest avoiding hydralazine. As far as mechanism of action is considered, the exact hydralazine mechanism is unclear but may appear to involve increased vascular nitric oxide or the ATP-sensitive potassium channel resulting in hyperpolarization. Man, that is just weird and repeated use of this agent may be associated with development of a lupus-like (SLE) syndrome and we do not need that kind of drama in the perioperative period. You probably won't ever see it due to a few doses in the OR—but pay attention, people, because we don't think we have ever seen a set of medical board pharmacology questions that did not include at least one question on hydralazine (or procainamide) and SLE. Additional perioperative contraindications to IV hydralazine use is the fact that it may interact adversely with over 100 commonly prescribed other medications.

Fenoldopam (interesting oddball drug) is an IV dopamine-1 specific agonist that induces natriuresis, diuresis, and has been used to treat hypertension, although comparative studies with established perioperative antihypertensive drugs like the dihydropyridines are sorely lacking. Its use probably does not protect the kidneys from injury in all perioperative clinical scenarios but the jury is still out on this question and it has been out for a long time. We do not recommend the perioperative use of fenoldopam to treat acute hypertension based on the lack of comparative trials.

Phentolamine (super oddball drug squared) is a peripheral alpha-receptor antagonist that is a poor choice of perioperative IV antihypertensive agent, primarily because of its associated risk of severe hypotension; however, it does have an established place in the management of patients with pheochromocytoma (which sadly is not a topic covered in this chapter). Remember that when treating pheochromocytoma, you need to vasodilate before you institute beta blockade, as opposed to a situation when you beta-block before you vasodilate, such as decreasing sheer stress in a patient with a dissecting aortic aneurysm. But otherwise, we recommend avoiding perioperative use of this agent.

Enalaprilat is an IV angiotensin-converting enzyme inhibitor that can reduce SVR related to the release of angiotensin II. However, because acute hypertension is most commonly related to disordered sympathetic discharge, we do not recommend perioperative use of this (weirdo) agent. It may come as no surprise that comparative studies involving this agent in the perioperative period are lacking as its mechanism of action is all wrong… unless the patient is hypertensive due the withdrawal of their angiotensin blockade.

Yet another oddball drug that may be used perioperatively is IV diltiazem (half-life 3.4 hours), a benzothiazepine that works by reducing arterial vascular tone and myocardial depolarization speed. Perioperative use of this agent is not recommended or common unless a patient is being treated with it as an outpatient and skipped a dose preoperatively resulting in excessive hypertension. In such cases, the dihydropyridines are still effective choices to rapidly gain BP control. Other clinicians may reach for this drug to control heart rate in patients developing atrial fibrillation with a rapid ventricular response. Its use should be strictly avoided in patients with significant hepatic impairment, renal impairment; and in those being treated with rifampin, bradycardia and arrhythmias can occur with its use.

The final oddball antihypertensive to mention is the phenylalkylamine calcium channel blocker IV verapamil (terminal half-life 2 to 5 hours). Verapamil acts as both a dilator of arterial smooth muscle and as a negative inotrope. It is commonly dosed in 5 mg to 10 mg increments at 5-minute intervals. It should be avoided in patients at risk of or with active congestive heart failure as it may induce or exacerbate this condition. Because, like labetalol, its mechanism of action is two-fold, it can have unpredictable effects on BP and is not recommended for regular perioperative use in BP management unless the clinician is well experienced with this agent.

## TAKE HOME POINTS

- For more complex patients with limited end-organ functional reserve, we here in Cleveland typically strongly consider using a noninvasive goal-directed therapy

blood pressure device (e.g., near-infrared finger cuff) to guide fluid therapy along with a cerebral oximeter to maintain vital organ perfusion with an effective mean arterial pressure. If these adjuncts are not available to you, or if your anesthetic plan does not include them, see Chapter 136 in the Perioperative section, which is devoted to selecting an effective blood pressure range for your patient.

- Remember MAP is a product of CO × SVR and SVR is the precisely titratable variable.
- The ideal perioperative antihypertensive drug is one that selectively targets systemic arterial vascular resistance and possesses a rapid onset, is easily and precisely titratable, has a short half-life, minimal drug-to-drug interactions, and limited dependence on organ function for metabolism. In many instances of acute perioperative hypertension, an ultrashort acting dihydropyridine is the choice agent.
- Beta-, alpha-, and mixed alpha-/beta-antagonists can be useful adjuncts for the treatment of acute perioperative hypertension, but be cautious in using these agents with patients that have limited heart rate reserve or that may be prone to congestive heart failure exacerbation.
- Nitrovasodilators (such as nitroprusside and nitroglycerin) have been shown to be poorly effective drugs in precisely controlling acute perioperative hypertension; their effectiveness is confounded by their lack of systemic arterial vascular selectivity and both multiple overshoots and undershoots of an appropriate target blood pressure range. Absolutely everybody who has ever used these drugs has experienced this.
- Avoid using IV clonidine in the treatment of acute perioperative hypertension as a primary antihypertensive agent unless a patient who is taking it chronically has skipped a dose in the perioperative period.
- Several oddball drugs exist as soft options for the treatment of perioperative hypertension. We recommend avoiding these agents in most clinical scenarios in favor of the dihydropyridines as comparative clinical trial data is lacking for these oddball agents that include the following: verapamil, diltiazem, hydralazine, fenoldopam, and phentolamine.
- Perioperative phentolamine use is still selectively used for management of patients with pheochromocytoma, but we think the dihydropyridines would work well in that situation given the mechanism associated with that pathology is ultimately sympathetic stimulation.

## Suggested Readings

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# Cardiovascular Vasoactive Drugs That Pump You Up

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A 72-year-old female presents for total abdominal hysterectomy related to painful, persistently bleeding leiomyomas. Her past medical history is significant for hypertension, diabetes mellitus type II, dyslipidemia, and peripheral vascular disease. During the preoperative assessment, she notes having taken her prescribed antihypertensive medications at 5 am which included atenolol, amlodipine, and lisinopril. She attests to not having eaten or taken liquids since 5 pm the prior day. Her vital signs at admission to the preoperative area are as follows: heart rate 65 beats per minute (regular), respirations 14 breaths per minute, blood pressure 137/65 mm Hg, and $SpO_2$ is 98% on room air. A recent cardiac workup found her to have a moderately reduced left ventricular ejection fraction of 40% and a pattern of multiple significant coronary occlusions for which she declined surgical intervention as she notes "I never have chest pain." Immediately after anesthesia induction her blood pressure drops to 61/22 mm Hg and diffuse ST-segment elevations are noted on the two monitored ECG leads (III and V4). What is going on and what is the move to make for this potentially bad clinical situation you have found yourself in?

Hypotension is commonly encountered in the perioperative period related to several factors. These most commonly include dehydration, hemorrhage, mechanical obstruction of venous return, and drug-induced sympathectomy. So knowing the various properties of the vasoconstrictors/inotropes is helpful to make an informed decision before you "pick your poison" and select the best agent to use in a specific clinical situation. Always keep in mind that blood pressure (BP) is related to both cardiac output (CO) and systemic vascular resistance (SVR), thus you must make a clinical judgment of whether the patient needs arterial tone, increased cardiac output, or both.

## Phenylephrine—Straight Up Alpha-1 Agonist

The "go to" vasoconstrictor for most anesthesia care providers is phenylephrine (half-life 5 minutes) which is preferred for its pure effect as an alpha-1 agonist, which of course means that it works as a vasoconstrictor of both systemic and pulmonary veins and arteries. Phenylephrine causes predictable decreases in venous capacitance and increases in systemic and pulmonary arterial tone under most clinical conditions regardless of the cause of the hypotension. Please take note that it initially vasoconstricts the venous circulation which can lead to a transient increase in cardiac preload which may increase CO and BP. However, with continued phenylephrine, use of the venous vasoconstriction will limit cardiac preload and, along with its effect on increased afterload, may significantly decrease cardiac output and limit its ability to increase BP in patients with limited cardiac reserve systolic function or in those significantly volume depleted. In addition, a mild reflexive decrease in heart rate may be observed with phenylephrine use as BP increases.

Phenylephrine is commonly dosed at 40 to 200 μg as an IV bolus and from 10 to 200 μg/min as an infusion. When dosing gets as high as 250 to 300 μg/min to maintain pressure you should consider a different strategy for maintaining BP such as volume administration or a more in depth evaluation of hemodynamics with a "rescue transesophageal echocardiogram" or invasive monitoring. As far as invasive monitoring is considered, a pulmonary artery catheter is not always needed. Consider inserting an arterial catheter combined with the use of a modified transducer possessing the ability to analyze the arterial waveform and give information on stroke volume and cardiac output, among other parameters. Commercially available devices include, but are not limited to, either an externally calibrated lithium dilution system (LiDCO, LiDCO Group plc, London, England) or a system autocalibrated to the patient based on their specific demographics (FloTrac, Edwards Lifesciences, Irvine, CA). Other systems are available and the reader is encouraged to review these devices as they all have specific strengths and weaknesses in different clinical settings. Combining the use of these hemodynamic parameters with the clinical situation can be very effective in guiding fluid balance and restoring vital organ perfusion in more challenging situations. In cases of hypotension not responsive to phenylephrine, volume administration and/or inotropic support are likely indicated. At concentrations of phenylephrine between 40 and 100 μg/mL it is considered safe to use in a peripheral vein. Greater phenylephrine doses mandate central access.

## Ephedrine—Indirect Acting at Beta-1 Receptors Through Release of Norepinephrine

The next most popular agent among perioperative uppers is IV ephedrine (half-life <1 hour, but up to 6 hours when dosed subcutaneously or intramuscularly). Despite its

relatively lengthy half-life, the clinical effect of ephedrine to increase BP seems only to last between 5 and 15 minutes. Ephedrine increases BP primarily by stimulating the release of norepinephrine (NE) from nerve terminals resulting in an increase in the inotropic and chronotropic state of the heart; thus, its primary ability to increase BP comes from an increase in CO, not vasoconstriction. In fact, the release of NE from nerve terminals following its administration causes arterial vasodilation and a drop in systemic vascular resistance. Under conditions where ephedrine is used repeatedly over short intervals (e.g., 5 to 10 minutes), one will observe tachyphylaxis as the nerve terminals become depleted of their NE stores.

Ephedrine is commonly dosed at 5 to 25 mg IV bolus, or 10 to 50 mg subcutaneously or intramuscularly; at a concentration of 5 mg/mL it is safe to inject via a peripheral vein or subcutaneously. Ephedrine is a better choice of bolus drug than phenylephrine to increase BP in individuals with limited cardiac reserve, but it cannot be relied upon to remain effective for repeated doses for the reasons stated. That said, it will buy you time to set up a drip of a mixed inotrope/pressor, such as dopamine, as opposed to flogging the heart possessing limited reserve function with a straight vasoconstrictor like phenylephrine.

## Dopamine—Dopamine Receptor Agonist and Beyond

Dopamine is another appealing choice of a perioperative upper that is marked by its ability to increase BP without producing isolated effects on systemic vascular resistance. Dopamine (half-life 2 minutes) is a naturally occurring catecholamine in the human body that, depending on the administered dose, acts to increase BP and CO through its effects at myocardial beta-adrenoreceptors. Dopamine also causes the release of NE from nerve terminals that may result in an increase in systemic vascular resistance.

At low-dose infusion rates (0.5 to 2 µg/kg/min), dopamine will act predominantly by agonizing dopaminergic receptors and will vasodilate the renal, mesenteric, and intracerebral vascular beds. An increase in urine output may also be observed in this dose range. Thus, although it may increase CO at low doses, it may also lower BP. At intermediate doses (2 to 10 µg/kg/mL), dopamine will stimulate beta-1 receptors in the myocardium resulting in an observed increased in both the chronotropic and inotropic state of the heart (i.e., increase in CO) which usually results in an increase in BP. Note that while it increases the sinus rate of the heart at intermediate doses, tachyarrhythmias are not common. At higher range doses of dopamine (10 to 20 µg/kg/min), the beta-1 effects are accompanied by alpha-1 effects that will result in a significant increase in BP but can limit the effectiveness of dopamine to increase CO as a result of the increased afterload. At dopamine doses above 20 µg/kg/min, the profound peripheral

vasoconstriction observed in skeletal muscle may be limb threatening and thus should be avoided. Standard concentrations of dopamine (400 mg/250 mL) are considered safe for use in a peripheral vein.

## Dobutamine—Beta-1 Receptor Agonist

Dobutamine (half-life 2 minutes, same as dopamine) is primarily a positive inotropic and chronotropic agent via beta-1 receptor stimulation and is used in patients with cardiac decompensation such as decompensated congestive heart failure. Blood pressure should be closely monitored as there are variable effects on this due to minor activity on alpha- and beta-2 receptors peripherally, and thus hypotension can be associated with its use. However, this decrease in SVR can aid in dobutamine's ability to increase CO. One caution to keep in mind, however, is use of dobutamine in patients with existing decreases in SVR, such as septic patients. These patients may become increasingly hypotensive with the use of dobutamine due to its beta-2 activity. The beta-1 stimulation associated with this drug can also cause patients to be prone to tachyarrhythmias such as atrial fibrillation, but less so than with dopamine. It is commonly used at doses of 5 to 20 µg/min and is safe for use in a peripheral vein at standard concentrations (1 to 5 mg/mL).

## Time to Change Gears…

If we have tried the softer stuff (phenylephrine, ephedrine, dopamine, and dobutamine—the Boy Scouts of the vasopressor/inotrope family) and found an unsatisfying effect, we have to pull out the big guns— NE, epinephrine, vasopressin, and methylene blue. These are the Navy Seals of the vasopressor drug cabinet.

## Norepinephrine (Levophed, aka Leave 'em Dead) Mixed Alpha-1>>Beta-1 Agonist

NE (half-life 1 minute) is the endogenous primary transmitter for the sympathetic nervous system (SNS). It acts on all alpha-receptors of the system and has some beta-receptor effects as well. It is released endogenously in very small quantities into the postganglionic synapse of the SNS. In this synapse, it has an extremely limited and short time of action before being retaken up into the postganglionic nerve terminal. NE also undergoes blood-borne release and acts endogenously via the stimulation of the adrenal medulla along with epinephrine (only 20% of this release is NE). When released in this way, NE half-life is much longer and has wider effects related to raising blood pressure. It is this naturally occurring pathway of release that allows us to use it now to support the cerebral and coronary perfusion. Now that we need a "big gun," the time has come to put in a central line. Although NE can be given through a peripheral IV the

preferred route is via a central access, due to the potential for extravasation-related necrosis. “Yeah, he survived but he looks like an extra in The Walking Dead!” Even centrally at high doses it can cause digital ischemia (ouch). It can also cause bradycardia and dysrhythmias is some patients but this is not commonly seen. What is common is massively increased vascular tone, everywhere, including the pulmonary vasculature, kidneys, GI tract, and as mentioned, the limbs. This can cause acidosis, potentially decreased cardiac output, increased right heart failure, acute renal injury, and intestinal ischemia (we did say it’s a big gun).

NE is traditionally given as a drip due to its short half-life. The drips are typically 4 mg/250 cc (16 µg/cc) or 8 mg/250 cc (32 µg/cc); these concentrations vary from institution to institution, so check your drug bag. Dosing is variable as well; some hospitals dose NE in µg/kg/min (0.01 to 3 µg/kg/min) while others dose in µg/min (2 to 20 µg/min). Because NE is an extremely potent vasopressor, it has become a well-used tool in the intensive care unit and operating room, especially for cardiac patients. Like we said, this is one of the big guns, certainly not the biggest, but often effective at giving you the pressor support you need. It is important to keep in mind that relative to epinephrine, NE is a much stronger alpha-1 agonist; however, both drugs are equipotent at the beta-1 receptor.

## Epinephrine—Mixed Alpha-1 <Beta-1 and -2 Agonist

Epinephrine (aka “Epi” or its screen name adrenalin from the famous “adrenalin shot” through the breast plate in the Pulp Fiction scene with Uma Thurman and Eric Stoltz) is another endogenous catecholamine that is made in the adrenal glands and is part of the human “fight or flight” response to stress. Epinephrine (half-life approximately 11 minutes) is both a beta-1 and beta-2 agonist more so than an alpha-1 agonist whereby it will produce less pronounced increases in systemic vascular resistance. Thus, clinically this agent is used to improve cardiac output through its effects on the beta-1 receptors eliciting both a positive inotropic and chronotropic response. It can also be useful to treat bronchoconstriction via nebulized inhalation of the drug or IV infusion due to its ability to agonize beta-2 receptors. It is pretty much the “go to drug” for the treatment of anaphylaxis and cardiac arrest or acute, severe cardiac decompensation.

The dosing varies depending upon the clinical situation. When used as an infusion to increase cardiac output, the dosing ranges from 0.01 to 0.1 µg/kg/min, but in select clinical situations doses as high as 0.5 µg/kg/min may be needed. In addition, for persistent hypotension while the epinephrine (and other drugs) are being titrated to appropriate support levels IV bolus dosing of anywhere within the neighborhood of 5 to 50 µg may be employed. For this reason, many of us were taught to draw up “big and little” epinephrine syringes for any case with the potential for hemodynamic lows. This

is generally a 10-cc syringe of epinephrine 100 µg/cc and one of epinephrine 10 µg/cc. For treatment of anaphylaxis, an initial IV bolus of 500 to 1,000 µg together with an infusion of 0.05 to 0.1 µg/kg/min (or higher) is commonly used. Use of IV epinephrine for the treatment of bronchospasm is commonly dosed in a lower range of 0.01 µg/kg/min.

Finally, on your darkest clinical days one may reach for what has been termed "super epi" which is epinephrine at a concentration of 1 mg/mL. This is for that "special patient" who deems doses of 0.5 µg/kg/min as inadequate to maintain hemodynamics. The concentrated formulation allows bolusing of super epi in the range of 0.5 to 10 mg at a whack. Usually these are patients that are not expected to survive without immediate institution of mechanical support therapy (left ventricular assist device or venoarterial extracorporeal membrane oxygenation) or aggressive volume resuscitation in the setting of acute, severe hemorrhage.

The downsides of epinephrine are tachyarrhythmias and hypertension. And keep in mind that in a pinch it can administered down the endotracheal tube (2 to 2.5 mg diluted in 10 mL of saline), intramuscularly or subcutaneously (both routes use a dose of 0.3 to 0.5 mg of 1 mg/10 mL concentration).

## Vasopressin (aka Antidiuretic Hormone, Arginine Vasopressin, or Argipressin)

If we are thinking of vasopressin (half-life 10 to 20 minutes), we are very likely standing in an ever-increasing pile of badness. Vasopressin (aka "vaso" in the clinical battle trenches) is an antidiuretic hormone analog, and was primarily certified for the treatment of diabetes insipidus. It has now found a role in the treatment of sepsis and vasodilatory shock states (e.g., postcardiopulmonary bypass vasoplegia). It is supplied in 20 unit/cc vials diluted to institutional concentrations, for example 40 units/250 cc (0.16 units/cc) or 20 units/250 (0.08 units/cc). The huge variability in concentrations is due to the rapid price increases in drugs that have effected certain generic drugs (vasopressin jumped 10-fold). Dosing for vasoplegia starts with a dose of 0.03 units/min and tops out 0.1 units/min, although many practitioners will not give over 0.06 units/min. Some practices dose in units/hour (3 to 9 units/hr). An additional use that is common in the OR is to bolus-dose as needed, much like phenylephrine (off-label use but then again, so was the Ghostbusters nuclear accelerator proton pack). In this role, one takes a 20 unit/cc vial and dilutes it to 1 unit/cc. Boluses are then given as 1 or more units at a time (depending on how deep the pile has gotten). The nice thing about vasopressin is that it uses the arginine vasopressin receptor for its actions, so it is helpful even when we have already "used" all the sympathetic nervous system receptors. We still need a central line as it has the same extravasation risk as NE. The

benefit is it has no effect on the pulmonary vasculature and is the drug of choice for right heart failure blood pressure support. This must be tempered with its large increase in peripheral vascular tone that can causes similar side effects to the other big gun NE (i.e., The Walking Dead syndrome). Vasopressin is a useful drug nonetheless given its use of a different receptor set for action. Keep in mind that vasopressin dosing is a bit like a light switch in that it is not frequently titrated (i.e., turn it on at 0.03 or 0.06 units/min and forget about it until the patient seems too hypertensive and then turn it off).

## Methylene Blue (Why Is My Pee GREEN?)

Remembering what we just said about the nonregulated nuclear accelerators (off-label), we are now firmly in that arena. If you have gotten here with a patient, it is bad, we mean crossing the streams bad. Methylene blue carries labeled use only for the treatment of methemoglobinemia. Its use as a vasopressor is a departure from that. It has been described only for post-CPB vasoplegia in the literature since 2004. Two dosing methods have been described. The first is one bolus dose of 1.5 to 2 mg/kg over 20 to 60 minutes. The second adds a 0.5 to 1 mg/kg/min infusion following the bolus dose. There are currently no clinical trials proving the above dosing regimens. Methylene blue carries the same extravasation risk as previously mentioned for NE and vasopressin. It can also cause a variety of other side effects and somatic symptoms that range from mild to serious, in pretty much every organ system. However, if we are giving methylene blue to manage post-CPB vasoplegia, fortunately the patient is asleep and intubated. Another big problem is serotonin syndrome if given to patients on specific serotonin reuptake inhibitors, NE reuptake inhibitors, or monoamine oxidase inhibitors. And this does happen. Thus, methylene blue is the last-choice pressor for the anesthesiologist when all else has failed in the postcardiopulmonary bypass, or similar, vasoplegic state. You use it if you have no other way to get your patient off the table.

### TAKE HOME POINTS

- First and most important is to **think** about what you are doing when you give a vasopressor drug. Higher numbers on the monitor are the byproducts of your manipulation of the patient's physiology, not the goal in and of itself. You must always think of BP as tightly linked to the two variables of systemic vascular resistance and cardiac output when selecting a treatment whether it be a drug or fluid administration or both.
- Intravenous phenylephrine is our first-line, everyday drug. It is the "go to" drug for most anesthesia clinicians and is pretty much a one-trick pony in that it is a pure alpha-1 agonist. Phenylephrine provides initial increases in venous tone (decreases

in venous capacitance) that transiently increases both cardiac preload and output but also hits the pulmonary and systemic arterial vessels and increases their tone. It is a nice drug but if you are giving bigger and bigger doses or your dosing gets outrageous, it is your job to reassess the patient and figure out what else the patient needs to support their hemodynamics. Generally, volume resuscitation and invasive monitoring will soon be following.

- Ephedrine is a useful drug to increase BP that acts primarily by stimulating the release of norepinephrine from nerve terminals resulting in an increase in the inotropic and chronotropic state of the heart; thus, its primary ability to increase BP comes from an increase in CO, not vasoconstriction. We repeat, ephedrine increases the blood pressure indirectly. It is not a vasoconstrictor. It acts on beta-1 receptors to stimulate the heart. Increases in blood pressure are due to increased cardiac output. Repeated doses cause tachyphylaxis and a waning effect of the drug, because the target nerve terminals become depleted of NE. If there is a tachyphylaxis question on the written boards, the answer is "ephedrine."
- Dopamine, a naturally occurring catecholamine, is a drug with multiple effects depending on the dose. Generally, the target use for dopamine is to act at the beta-adrenergic sites in the myocardium to increase CO and BP. It will also cause NE release and increase SVR. These are ubiquitous topics on the written board exams, so study the above paragraphs and the following summary carefully. Dopamine is a more complex drug in that its effects on the dopaminergic receptors will ultimately depend on the dosing range. At lower doses of 0.5 to 2 μg/kg/min dopamine will selectively dilate various vascular beds and produce a natriuresis; thus it may lower BP at this dose range. At intermediate doses of 2 to 10 μg/kg/min it will stimulate the release of catecholamines that will agonize the cardiac beta-receptors (chronotropic and inotropic effects) as well as peripheral alpha-receptors. The intermediate doses effectively raise BP by increasing CO and SVR. At higher doses of 10 to 20 μg/kg/min, dopamine will continue to have beta effects that promote CO but also much stronger alpha-induced vasoconstrictive effects that can reduce the observed increase in CO. Also note that at the high dose range there can be profound vasoconstriction that may lead to peripheral tissue ischemia.
- Dobutamine is a mostly inotropic drug that acts by stimulating beta-1 receptors to increase CO and is commonly used in the treatment of decompensated congestive heart failure. Dobutamine also has some peripheral beta-2 effects that can result in hypotension. Use dobutamine with caution in patients with septic shock (i.e., those already vasodilated) and note that its use can be associated with tachyarrhythmias due to its beta-1 agonism.
- Norepinephrine is the first of the big guns to turn to. It is also an endogenously produced catecholamine, with enormous alpha-receptor effects and minor beta-1 agonism. Note that this agent has equipotent beta-1 effects compared to epinephrine

but its alpha-1 effects are far more potent than epinephrine. It generally mandates central access as extravasation is a significant problem. Expect that there will be robust or even massive increases in the vascular tone of the kidneys, lungs, GI tract, and extremities. This drug works but you can suffer a lot of complications and side effects, so you must watch and titrate extremely carefully. At higher range doses without adequate cardiac output the profound systemic vasoconstriction can cause peripheral ischemia (i.e., what we like to call The Walking Dead Syndrome).

- Epinephrine, like norepinephrine, is a mixed beta- and alpha-agonist; however, its beta-1 and -2 effects are more pronounced than its alpha-1 effects. This agent is commonly used in the treatment of anaphylactic shock and cardiogenic shock. At very low doses it can be an effective treatment for bronchoconstriction. In the form of "Super Epi" (i.e., epinephrine 1 mg/mL) at high bolus doses of 1 to 10 mg, it can serve as short-term bridge treatment to maintain vital organ perfusion during hypovolemic or cardiogenic shock, so think of it when you are really in a hemodynamic pinch. One of our clinical mentors once said, "You may only use emergency epinephrine once every 100 cases but when you need it, you need that and only that and you need it quickly. So your epi syringes need to be ready, clearly marked, and waiting in their own little piece of real estate on your anesthesia cart."
- Epinephrine is another pressor that has variable effects depending on the dose, so you will need an extra study card for this drug when preparing for the boards. Of course, don't forget that this is one of the drugs that can be administered via the endotracheal tube.
- Vasopressin is used off-label for dire circulatory shock situations such as post-CPB vasoplegia. The use of the drug is for an advanced clinical threat, especially when you need a drug whose pressor action involves a different set of receptors—primarily the arginine vasopressin receptors in the vasculature—instead of the sympathetic nervous system receptors. In short, vasopressin is another treatment option for low SVR that occurs through a dedicated effect of this agent at the vasopressin receptor which results in increased SVR and BP (if cardiac output is being maintained).
- Vasopressin is commonly used in cardiac surgical or low-tone septic patients that demonstrate vasoplegia. It is important to note that it can be a useful treatment to maintain vital organ perfusion in right heart failure as there are no vasopressin receptors in the pulmonary arterial vasculature. Overuse of vasopressin without adequate cardiac output can also precipitate end-organ ischemia due to profound vasoconstriction.
- Methylene blue is what many anesthesiologists may call the "Hail Mary play" for treating profound vasoplegia and its effectiveness is tentative at best in our experience. We reserve its use for those patients with profound, refractory vasoplegia and starting with the recommended bolus. If we see an effect from the

bolus, we think it makes sense to start the drip; otherwise you may need to say a prayer for the patient. Its use can be associated with serotonin syndrome, so strictly avoid its use in patients taking specific serotonin reuptake inhibitors, norepinephrine reuptake inhibitors, and monoamine oxidase inhibitors.

**Note from the authors:** If you are young and haven't watched the original 1984 Ghostbusters, do yourself a favor on your next post call day and indulge. There have been remakes, but Ernie Hudson, Bill Murray, Dan Aykroyd, and the late great Harold Ramis did it first and best. It won't help you choose the best vasopressor (that's our job) but will give you a laugh and help with the ever-present work-life balance problem. The same goes for Pulp Fiction—no better way to shake off a really arduous night of call than with a quick immersion into the dark wit and wisdom of Quentin Tarantino.

## Suggested Readings


Levin RL, Degrange MA, Bruno GF, et al. Methylene blue reduces mortality and morbidity in vasoplegic patients after cardiac surgery. Ann Thorac Surg. 2004;77(2):496–499.

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# Milrinone—The Not-So-Kidney-Friendly Intraaortic Balloon Pump in a Bottle

James Jonna, MD and Edwin G. Avery IV, MD

A 68-year-old male with ischemic cardiomyopathy and severe, functional mitral regurgitation presents for coronary revascularization and mitral valve repair surgery on cardiopulmonary bypass (CPB). His past medical history is significant for both systolic (left ventricular ejection fraction 25%) and diastolic heart failure, hypertension, hyperlipidemia, stage 3 renal dysfunction (Glomerular Filtration Rate 30 to 59) as well as severe arterial atheromatous disease. The patient's arterial disease is noted to be especially severe in the descending thoracic aorta with documented Grade V (mobile atheromas) disease. The surgeon plans for five coronary arterial bypass grafts, a ring annuloplasty of the mitral valve, as well as a left ventricular papillary myoplasty with GOR-TEX chordae which is expected to extend the longevity of his mitral repair by preventing further papillary muscle displacement. Your patient's anesthesia induction is gratefully uneventful after being supplemented with a prophylactic intravenous infusion of dopamine at 10 μg/kg/min which improved/maintained inotropy, chronotropy, and systemic vascular resistance despite the sympathectomizing nature of our induction drugs (fentanyl, midazolam, and propofol). You cruise through to the initiation of CPB and are feeling pretty good about this tough case and think to yourself "What could possibly go wrong now? I'm killin' it today in the heart room!" Well, following a 4-hour run on CPB it is apparent that there is severe biventricular systolic dysfunction by intraoperative transesophageal echocardiographic (TEE) examination, pulmonary arterial pressures are elevated by 30% above baselines, and both systemic blood pressure (MAP 50 mm Hg) and systemic vascular resistance (500 dynes • sec • $cm^{-5}$) are unacceptably low while the cerebral oximeter is reading critical desaturations (25%+ below baseline) bilaterally. Urine output on CPB was good at about 2 mL/kg/hr. What is your next move? Are you out of your league for drugs and are thinking mechanical support? Is there another approach that might better serve this patient?

## The 30,000 Foot View of Clinical Milrinone Use

Anesthesia clinicians outside of the cardiac room will have rare cause to reach for milrinone. Use of this drug is reserved for patients whose hearts are really limping (like the one in our clinical vignette that got a 4-hour long kick in the shin on CPB). Its ability to reproducibly significantly improve inotropy, cardiac index, and diastolic function have earned it the nickname "intraaortic balloon pump in a bottle." Because there is no such thing as a "free lunch" you'll have to keep in mind that along with these effects also comes a few other issues, most notable of which is systemic vasodilation which invariably precipitates the need for a vasoconstrictor when milrinone is administered with a full loading dose and continuous infusion, especially in anesthetized patients. Its ability to increase cardiac index is in part related to the drop in systemic vascular resistance that it causes, so adding a vasoconstrictor (i.e., increased afterload on both the left and right heart) is going to cost you a reduction in the observed gains you will see from just using straight milrinone. In many awake (i.e., nonanesthetized) heart failure patients that are being treated with milrinone, they can tolerate the drug without addition of an intravenous vasoconstrictor as they are not under the sympathectomizing influence of our anesthetic drugs, such as volatile anesthetic gases and narcotics. Furthermore, many cardiologists will start their awake ICU heart failure patients on milrinone without the loading dose bolus and just let the level rise to steady state over 6 to 12 hours giving the body time to compensate for the drop in afterload caused by milrinone.

In the acute situation described in our vignette we do not have the luxury of time to allow the milrinone level to slowly rise without administering the loading dose. Many clinicians will try to use milrinone without a bolus or will incrementally load the patient as tolerated while they coadministered another inotrope with both beta- and alpha-adrenergic effects such as epinephrine or norepinephrine. For example, in our practice in Cleveland, we will examine the systolic function of the heart on partial bypass to gauge the systolic function and then if it is assessed as being severely depressed we will give anywhere from 25% to 100% of the appropriate milrinone load in increments while directly examining biventricular systolic function with TEE as well as start the milrinone infusion at an intermediate dose of 0.5 μg/kg/min. To effectively counterpunch the inevitable vasodilation you'll need to put on your thinking cap. If the vasodilation is mild then epinephrine or norepinephrine at a modest dose (e.g., 0.025 to 0.05 μg/kg/min) may be sufficient to keep the systemic vascular resistance in the normal range (i.e., 800 to 1,200 dynes • sec • $cm^{-5}$). If the vasodilation is more severe, as seen in our clinical case, and is likely related to excessive release of inflammatory mediators such as bradykinin with vasodilatory properties during the long CPB run, then higher doses of norepinephrine may be needed (e.g., 0.1+ μg/kg/min). Alternatively, in the case

where right ventricular systolic failure is a major issue it makes sense to start your efforts to abate milrinone-associated systemic vasodilation with vasopressin as there are no vasopressin receptors in the pulmonary arterial circulation. This allows milrinone to work on ratcheting up right ventricular inotropy and lusitropy while decreasing right heart afterload. Indeed, as mentioned in Chapter 241, the drug cocktail of milrinone, vasopressin, and inhaled nitric oxide (or inhaled epoprostenol) is what Rodney Dangerfield would call "The Triple Lindy" of right heart failure treatments. And while we are mentioning inhaled drugs there is some literature supporting the use of inhaled milrinone for the treatment of pulmonary hypertension and/or right heart failure which may abate some of the systemic vasodilation seen when it is used intravenously. Intravenous milrinone may also be used to specifically treat pulmonary hypertension in the perioperative setting but this is not something we do in our practice as we have access to inhaled nitric oxide which is a therapy that is focused on treating isolated pulmonary hypertension.

A few final thoughts related to clinical milrinone use is that it will rise to much higher plasma levels in patients with compromised renal function, so dosing should be more conservative as discussed later in this chapter. In addition, milrinone can represent an excellent alternative to mechanical circulatory support with an intraaortic balloon pump in patients with severe aortic atheromatous disease like the one described in our clinical case as this will put them at higher risk for downstream thromboembolic complications. Finally, beta-agents in combination increase cAMP via beta-receptor activation while inhibition of phosphodiesterase III prevents its breakdown, so you have two different mechanisms that may be advantageous in combination.

## Milrinone: Mechanism of Action

Milrinone is a selective inhibitor of peak cAMP phosphodiesterase III isozyme in cardiac and vascular smooth muscle. Milrinone replaced amrinone (inamrinone), which was another phosphodiesterase inhibitor that often resulted in a fair amount of drug-induced thrombocytopenia. The inhibitory action of milrinone on phosphodiesterase results in increased cAMP levels, which in turn increases contractility in cardiac muscle as well as increases the speed of contraction and relaxation (i.e., lusitropy) and stimulates vasodilation in blood vessels. This causes an increase in cardiac output and a decrease in pulmonary wedge pressure, or pulmonary vascular resistance. These hemodynamic changes are obtained without excessive changes in heart rate or increase in myocardial oxygen consumption. On a clinical note, beta-agents in combination increase cAMP via beta-receptor activation while inhibition of phosphodiesterase III prevents it breakdown, so you have two different mechanisms that may be advantageous in combination.

## Milrinone: Indications

Milrinone's use has been best studied in patients with congestive heart failure. It appears to be very efficacious in nonhypotensive patients with acute nonischemic cardiomyopathy (including Takotsubo cardiomyopathy) despite treatment with diuretics. These patients benefit from an enhancement in contractility and afterload reduction. In addition, milrinone is known to provide enhanced diastolic function. Duration of therapy should last for 48 to 72 hours; however, individuals awaiting heart transplant or recovery from viral, peripartum, or idiopathic cardiomyopathy may be maintained on intravenous milrinone for weeks to months. There are no studies to date that support its use for a longer period. Long-term oral therapy with milrinone has been associated with increased mortality.

## Milrinone: Dosing

The recommended dose in patients with normal renal function is a 50 µg/kg bolus followed by a continuous infusion at 0.375 to 0.75 µg/kg/min. The loading dose of milrinone should be given slowly over 10 minutes or longer, depending on the clinical situation. It should also be noted that some cardiologists will use maintenance doses at low as 0.2 µg/kg/min in patients with renal insufficiency. Because milrinone is excreted mainly through the kidneys, its dose in patients with renal impairment should be adjusted accordingly (by surface area) (CrCl denotes creatinine clearance):

- CrCl 50 mL/min/1.73 $m^2$: Administer 0.43 µg/kg/min.
- CrCl 40 mL/min/1.73 $m^2$: Administer 0.38 µg/kg/min.
- CrCl 30 mL/min/1.73 $m^2$: Administer 0.33 µg/kg/min.
- CrCl 20 mL/min/1.73 $m^2$: Administer 0.28 µg/kg/min.
- CrCl 10 mL/min/1.73 $m^2$: Administer 0.23 µg/kg/min.
- CrCl 5 mL/min/1.73 $m^2$: Administer 0.2 µg/kg/min.

An immediate improvement in hemodynamics is seen within 5 to 15 minutes after initiation of therapy. The mean half-life of milrinone is approximately 2.4 hours, and patients reach a steady-state plasma milrinone concentration (200 ng/mL) within 6 to 12 hours of a continuous maintenance infusion of 0.50 µg/kg/min. The impact of the half-life of milrinone is clinically important, as the effects of the drug cannot be "turned off" rapidly as can those of many of the other commonly used inotropic agents, such as epinephrine. Similar to achieving a steady-state of milrinone with a constant infusion one can expect the clinical effects of milrinone to take up to 6 to 12 hours to fully abate.

## Milrinone: Cautions In Use

Milrinone decreases atrioventricular nodal conduction time, allowing a potential for

increased ventricular response rates (up to 3.8%) for patients with supraventricular arrhythmias. Ventricular arrhythmias (ventricular ectopy, sustained and nonsustained ventricular tachycardia) have also been reported in up to 12% of patients. Life-threatening ventricular arrhythmias appear to be related to the presence of other underlying factors such as a pre-existing arrhythmia and/or metabolic abnormalities. Extreme caution must be used in patients with renal compromise. Fatal ventricular arrhythmias developed in six of nine patients in a recent study of the pharmacokinetics of milrinone in patients on continuous venovenous hemofiltration (CVVHD). These patients were oliguric (<400 mL/24 hr) and had a serum creatinine of >2.0 mg/dL. All patients received 0.25 μg/kg/min of milrinone and developed a mean steady-state concentration of 845 ng/mL, four times higher than that of patients with normal renal function. The high protein-binding affinity of milrinone and decreased urinary excretion could have contributed to this high concentration, thereby leading to the increased incidence of ventricular arrhythmias.

We would also like to finally note that of course you must always consider volume as part of the "milrinone equation" as the vasodilation caused by this drug will go a long way toward causing hemodynamic issues in the hypovolemic patient, as mentioned above. This seems like a basic concept, but we make the point to our readers that the fact that milrinone is considered an inotrope might cause clinicians who are not extremely familiar with the drug to assume that it, by itself, will completely improve hemodynamic outcome.

We like to think of milrinone use in some clinical situations as whipping the dying proverbial horse (we would never whip a real horse, that's just not our bag, **of course**) except instead of a proverbial horse we are whipping the dying heart muscle. Whipping it might improve its function for a stretch but don't be surprised if the heart bottoms out and fires off a malignant arrhythmia if you keep blasting it with milrinone. The presence of malignant arrhythmias in milrinone-treated patients likely herald the need for "advanced mechanical circulatory support." By that, we mean left ventricular assist device or venoarterial extracorporeal membrane oxygenation, and the ICU nurses aren't going to be happy to hear it…might be a good idea to buy the ICU team pizza or sub sandwiches before you announce the bad news!

## TAKE HOME POINTS

- Milrinone is a phosphodiesterase inhibitor that acts primarily on cardiac and vascular smooth muscle. Its effects are to increase cardiac output through increased inotropy and reduced cardiac afterload (decreased pulmonary and systemic arterial resistance) as well as enhance diastolic function (lusitropy) which have ultimately

earned it the nickname “intraaortic balloon pump in a bottle.”

- Milrinone may be given intravenously for a period of 48 to 72 hours, but therapy may be continued for weeks to months in patients awaiting heart transplant or those with peripartum, viral, or idiopathic cardiomyopathy that await functional recovery. It has a mean half-life of 2.4 hours—its effects cannot be just turned off as most inotropes can because its longer half-life means that it will take up to 6 to 12 hours for its clinical effects to fully abate following discontinuation of infusion.
- Milrinone loading, especially in anesthetized patients, can result in significant systemic hypotension which will frequently require treatment with some form of vasoconstrictor or combined inotrope/vasoconstrictor. Use of inhaled milrinone to focus on treatment of pulmonary hypertension may reduce the systemic vasodilatory effects seen with intravenous milrinone use.
- Extreme caution must be used in patients with renal failure because of the potential to develop supratherapeutic plasma levels with associated life-threatening arrhythmias.
- The occurrence of malignant arrhythmias in milrinone-treated patients may signal the need for mechanical circulatory support.
- For patients with renal compromise, the milrinone dose must be adjusted on a sliding scale.
- Milrinone (aka intraaortic balloon pump in a bottle) can represent an excellent alternative to a real intraaortic balloon pump in patients with severe aortic atheromatous disease who are at increased risk of thromboembolic complications.

## Suggested Readings


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# Amiodarone and Alternative Antiarrhythmics—Double-Edge Swords for the Treatment of Atrial and Ventricular Fibrillation

Muhammad Durrani, MD, Alan Cheng, MD, and Edwin G. Avery IV, MD

A 68-year-old male with a history of prostatic cancer is scheduled for robotic prostatectomy. Past medical history is significant for mitral valve prolapse with associated moderate mitral regurgitation, moderate to severe left atrial dilation, mild pulmonary hypertension, systemic hypertension, morbid obesity, and 1-year history of paroxysmal atrial fibrillation. The patient is not aware of when he is in atrial fibrillation and notes no activity limitations in his daily life which he admits is a rather sedentary lifestyle. His medications include metoprolol, amlodipine, and a baby aspirin. He was encouraged to start anticoagulant therapy but declined to do so related to his perceived lack of symptomatology. In the OR his baseline vitals are as follows: temperature 36.6°C, heart rate 68 beats per minute (regular), respirations 17 breaths per minute, blood pressure 146/86 mm Hg, and oxygen saturation of 96% (room air). He had taken all his antihypertensive medications on the morning of surgery as instructed preoperatively. He tolerated induction reasonably well with some hypotension down to 89/47 mm Hg which responded well to a dose of ephedrine 10 mg intravenously. The case progressed uneventfully after positioning and abdominal $CO_2$ insufflation for about 45 minutes when his heart rate abruptly increased to 150 beats per minute (irregularly irregular) without any change in surgical stimulation. The ECG tracing is consistent with atrial fibrillation with a rapid ventricular response. The blood pressure is 66/34 mm Hg, oxygen saturations are 99% with an $FiO_2$ of 0.7. The surgeon notes that the peritoneal tissue looks dusky. What is your first move to stabilize the patient? Is there a role for cardioversion and what risk may be associated with that therapy? What pharmacotherapy might be indicated in this situation? Does the pharmacotherapy have any implications for drug–drug interactions?

## 30,000 Foot View of Amiodarone and Alternative

## Antiarrhythmic Agents

Drugs like amiodarone and other alternative antiarrhythmic agents are genuinely the double-edged swords of pharmacotherapeutics—pretty much all these agents **can terminate as well create cardiac arrhythmias**. When it comes down to treating a common arrhythmia like atrial fibrillation (AFIB), there are a number of therapeutic approaches that include drugs, synchronized electrical cardioversion, percutaneous unipolar radio frequency ablation (RFA), open chest bipolar (RFA), and semi-invasive thoracoscopic bipolar RFA. Anesthesia clinicians are most commonly going to be managing acute AFIB-related issues with either drugs or synchronized cardioversion while the RFA options are reserved for therapy occurring in more of an elective setting. The overall panel of drugs certainly provides very good clinical options. However, most anesthesia clinicians only get training and experience using just a few of the antiarrhythmics. **So we need to be knowledgeable of the most versatile and effective antiarrhythmic drugs while the less commonly used drugs are left to our cardiac electrophysiology colleagues to handle. Amiodarone fits the bill for a versatile antiarrhythmic agent, so this chapter will focus mainly on it as well as a few other agents that can be helpful to manage AFIB.** If we go to 31,000 feet and look at the view from there, we have to remind the reader that amiodarone appears in the ACLS protocol and we feel strongly that the "generalist" anesthesiologist and anesthesia care provider should be able to use it comfortably and confidently. Unfortunately, the clinical need for amiodarone is statistically uncommon and it is not a drug that most anesthesiologists will typically reach for, unless they are coding a patient.

Before moving on to discuss amiodarone and the like, we think it important to stress one of the clinical features associated with AFIB and that feature is the increased stagnation of blood that occurs in the atria. This lower blood velocity in the left atrial appendage (LAA) puts the AFIB-afflicted patient at risk for systemic thromboembolic complications. What this really boils down to from a clinical standpoint is that any time we treat AFIB with electrical therapy, or any other arrhythmia for that matter, there is a risk of thromboembolic events. That said, in general we are going to reserve the application of electrical therapy for the following two clinical situations: (1) we know for sure that the patient has been therapeutically anticoagulated for a period of approximately 4 to 6 weeks, so the likelihood of clot existing in the LAA is very low, or (2) the patient's hemodynamic status is not amenable to waiting to figure out if there is thrombus in the LAA and we are worried about a watershed cerebral stroke/anoxia, so we go ahead with electrical cardioversion and accept the thromboembolic stroke risk. In situations where the hemodynamic stability is borderline and the resources are available, it makes sense to start treatment with pharmacotherapy while arrangements are made for a focused STAT transesophageal echocardiographic examination of the

LAA by a qualified clinician, for example, an Advanced NBE-certified cardiac anesthesiologist or NBE-certified cardiologist.

As far as the patient in our clinical vignette, he appears to be set up for a possible clot in the appendage (i.e., he can't tell when he is in AFIB and is not anticoagulated), so we suggest avoiding the immediate use of a synchronized cardioversion and to temporize him by initiating therapy with a systemic vasoconstrictor (e.g., phenylephrine) to improve end organ perfusion. And if that is successful, then we would get a STAT TEE (if available) to rule LAA clot. If the TEE is negative and hemodynamics are still shaky then a synchronized cardioversion is worth a try, especially if additional beta-blocker is also administered to help keep him from speeding up again. If rescue TEE is not immediately available we would administer an intravenous esmolol bolus to attempt to control the rate which would be expected to stabilize the hemodynamics and avoids the downsides of amiodarone (i.e., more hypotension). If the short-acting beta-1 specific blocker (esmolol) is effective then we would follow up with a longer-acting intravenous beta-1 specific agent like metoprolol to sustain rate control. At this point it would be a great idea to get an arterial blood gas to check electrolytes to ensure they are optimized and make sure that the $PaCO_2$ isn't too high from all the abdominal $CO_2$ insufflation. If hemodynamics remain stable the procedure could be completed and cardiology could consult on the patient in the PACU. There are many ways to skin a cat (and we don't advocate for any harmful actions to cats even though everyone knows dogs are a man's or woman's best friend), so this is just one approach to this clinical dilemma!

## The Basics of AFIB and Amiodarone

Atrial fibrillation is a common arrhythmia in both the intensive care unit (ICU) and perioperative cardiothoracic surgery settings. The mainstay of therapy is rate control, with beta-blockers being the first-line agents. In more acute clinical situations that involve significant hemodynamic deterioration, synchronized, direct-current cardioversion is immediately indicated. Frequently, however, the decision is made to use rhythm-converting agents, such as amiodarone. Amiodarone is a complex antiarrhythmic agent (predominantly class III) that shares at least some of the properties of each of the other three Vaughn-Williams classes of antiarrhythmics. Amiodarone is commonly used for the treatment and prevention of persistent atrial and ventricular tachyarrhythmias, although it is approved by the U.S. Food and Drug Administration (FDA) only for management of ventricular arrhythmias. It is one of the few agents that can be used safely in individuals with congestive heart failure. Contraindications to amiodarone include severe sinus node dysfunction with marked sinus bradycardia or syncope, second- or third-degree heart block, known hypersensitivity to its contents,

cardiogenic shock, and probably severe chronic lung disease.

Amiodarone is highly lipid-soluble, extensively distributed in the body, and highly concentrated in many tissues, especially in the liver and lungs. After variable (30% to 50%) and slow gastrointestinal (GI) absorption, amiodarone is very slowly eliminated with a half-life of about 25 to 110 days. The onset of action after oral administration is delayed, and a steady-state drug effect may not be established for several months unless large loading doses are used. It is important to note that when multiple loading doses of amiodarone are administered, for example, 4 to 6 separate intravenous boluses of 150 mg of the drug in the time span of an hour to 2, the likelihood of developing an acute respiratory distress syndrome (ARDS) approximately 2 weeks later is a significant risk. Amiodarone undergoes extensive hepatic metabolism to the pharmacologically active metabolite, desethylamiodarone (DEA). Amiodarone is excreted not by the kidneys but rather by the lacrimal glands, the skin, and the biliary tract. Neither amiodarone nor DEA is dialyzable.

Amiodarone is both an antiarrhythmic and a potent vasodilator. Amiodarone lengthens the effective refractory period by prolonging the action-potential duration in all cardiac muscles, including bypass tracts (class III activity). It also has a powerful class I antiarrhythmic effect that works by inhibiting inactivated sodium channels at high stimulation frequencies. Amiodarone slows phase 4 depolarization of the sinus node as well as conduction through the atrioventricular node. It also decreases $Ca^{2+}$ current (class IV effect) and transient outward delayed rectifier and inward rectifier $K^{+}$currents. Amiodarone noncompetitively blocks α- and β-adrenergic receptors (class II effect); this effect is additive to competitive receptor inhibition by beta-blockers. Thus, bradycardia and hypotension related to the beta-adrenergic effects can occur with rapid amiodarone administration; these side effects should be on the top of your “watch list” when bolusing this agent.

Other notable acute effects include hypokalemia and interactions with numerous medications such as Coumadin and digoxin (see below), and, rarely, torsades de pointe. There is a risk of pulmonary toxicity with high doses, starting with pneumonitis (i.e., ARDS-like syndrome in some more extreme cases) and leading to pulmonary fibrosis. Other organ systems affected by amiodarone therapy include the thyroid (hypothyroidism or hyperthyroidism), the central nervous system (proximal muscle weakness, peripheral neuropathy, and neural symptoms), and the gastrointestinal tract (nausea 25%, elevated liver functions), and it may cause testicular dysfunction, corneal microdeposition, and photosensitive slate-gray or bluish skin discoloration.

Agents that can be considered as alternatives to amiodarone for the treatment of atrial fibrillation depend on the patient’s cardiac history, as individuals with reduced left ventricular systolic function are especially prone to the proarrhythmic effects of

certain antiarrhythmic agents. Some commonly used alternatives include ibutilide, dofetilide, and sotalol. Strong consideration should be given to obtaining consultation with a cardiac electrophysiologist before initiating these agents.

Ibutilide prolongs repolarization by inhibition of the delayed rectifier potassium current (Ikr) and by selective enhancement of the slow inward sodium current. This drug is efficacious in the termination of atrial fibrillation and flutter with both single and repeated intravenous infusions. It is as effective as amiodarone in cardioversion of atrial fibrillation. The proarrhythmic effect resulting in torsades de pointe is higher in individuals with heart failure, those with bradycardia, nonwhite subjects, women, and in those given the drug for atrial flutter rather than atrial fibrillation. The risk of this is greatest during or shortly after the infusion of the drug (within 1 hour) and wanes rapidly after administration because the half-life (2 hours to 12 hours) of this agent is short. The patient should be monitored for at least 4 hours after the start of the infusion.

Dofetilide prolongs the action potential and QTC in a concentration-related manner. Dofetilide exerts its effects solely by inhibition of the rapid component of the delayed rectifier potassium current Ikr. Dofetilide has stronger evidence in its favor for acute cardioversion of atrial fibrillation than for maintenance thereafter, according to a meta-analysis. It can be given to patients with depressed function but needs to be initiated while being continuously monitored on telemetry for the first 3 days of therapy because this too, like ibutilide, carries a risk of proarrhythmia. The risk of torsades de pointes can be reduced by establishing or maintaining normal serum potassium and magnesium levels, predose adjustment of renal function, and postdose reduction based on $QT_C$ (ideally, baseline $QT_C$ <429 milliseconds). Administration of dofetilide requires that the hospital and the prescriber be trained as confirmed administrators. Further information can be found at www.tikosyn.com.

Sotalol has combined class II and class III properties, is active against a variety of arrhythmias, and has the ability to produce profound bradycardia or prolongation of the QT interval. Of the many indications, sotalol is most commonly used for maintenance of sinus rhythm after cardioversion for atrial fibrillation and for reducing ventricular tachyarrhythmias. Despite its ability to prevent tachyarrhythmias, sotalol (like any other antiarrhythmic) can also be proarrhythmic because of its ability to profoundly prolong the QT interval. As a result, initiation of this drug should occur while the patient is closely monitored. At some institutions, outpatients are admitted to the hospital to initiate oral sotalol therapy. Sotalol is contraindicated in patients with reduced creatinine clearance (<40 mL/min) and asthma. It should be avoided in patients with serious conduction defects, in patients with bronchospastic disease, and when there are evident risks of proarrhythmia.

## Drug–Drug Interactions (DDIs) Involving Amiodarone

Amiodarone is notable for being a paninhibitor of cytochrome P450 (CYP) enzymes. In the recently published DDI handbook and reference text A Case Approach to Perioperative Drug-Drug Interactions (Springer, 2015), it is noted to be one of the forty most "active" drugs in terms of clinically relevant DDIs. Amiodarone is extensively metabolized to desethylamiodarone, which itself is a marked inhibitor of CYP 2D6. Enzymatic inhibition will not occur with loading or even brief doses of amiodarone but since inhibition of CYP enzymes generally occurs in the time frame of a few days, there can be significant implications in the later perioperative course. In the above referenced text, the authors detail the specific pharmacology in several teaching "cases" involving interactions between amiodarone and amitriptyline, metoprolol (a CYP 2D6 substrate), warfarin, and digoxin. Amiodarone also has pharmacokinetic interactions with various other therapeutic agents such as phenytoin, flecainide, and cyclosporine. Finally, to finish our brief DDI discussion, we would like to add a line of consideration of the QT interval when treating nausea and/or vomiting in these patients. The propensity to cause torsade de pointes with these potassium blockers (especially sotalol, Ibutilide, dofetilide) may be accentuated by addition of other things that cause QT-prolongation (e.g., droperidol, ondansetron) and consideration of therapy of this drug-induced torsades with magnesium is warranted when it occurs.

## Summary

The use of these antiarrhythmic medications must be undertaken in a clinical environment with the appropriate resources to deal with the complications that may accompany their use. Specifically, these drugs should be used only in care settings with immediately available emergency resuscitation equipment (e.g., code cart with emergency drugs, airway equipment, defibrillator, and pacing devices) as well as personnel appropriately trained (anesthesiologists, intensivists, or cardiologists) to use this equipment.

### TAKE HOME POINTS

- Amiodarone and other alternative antiarrhythmics are truly double-edged swords of cardiac pharmacotherapeutics in that they can both treat and create arrhythmias; thus they must always be used with full knowledge of their risks and merits.
- AFIB is a common perioperative arrhythmia, especially in cardiothoracic surgical patients or in those with a diagnosis of paroxysmal AFIB; the mainstay of AFIB therapy is rate control.
- AFIB is most commonly managed in the perioperative setting with the use of drugs

as the use of synchronized cardioversion may put the patient at risk for thromboembolic events.

- Synchronized cardioversion may be necessary if pharmacotherapy does not stabilize the patient and they are assessed as being at high risk for a watershed cerebral stroke due to inadequate hemodynamic status.
- If at all possible, a rescue TEE by a qualified clinician should be considered prior to synchronized cardioversion of AFIB to rule out LAA thrombus and mitigate stroke risk.
- Amiodarone can be useful to pharmacologically convert AFIB or ventricular fibrillation to an organized rhythm. When we are teaching in the OR or other informal settings, we teach that amiodarone use for ventricular fibrillation is usually a very "sick heart situation." For example, our personal most common use of amiodarone is while the patient is still on CPB with the aortic cross clamp off, the heart is defibrillated but keeps popping back into ventricular fibrillation.
- Known side effects of amiodarone administration include the following: bradycardia, hypotension, hypokalemia, torsades de pointe, pulmonary toxicity with high doses, pulmonary fibrosis, hypothyroidism, hyperthyroidism, proximal muscle weakness, peripheral neuropathy and neural symptoms, nausea, elevated liver enzymes, testicular dysfunction (yikes), corneal microdeposition, and photosensitive slate-gray or bluish skin discoloration. (If I were a radio/TV announcer I would read this bullet point at top speed so nobody would catch how many side effects this drug has.)
- An additional side-effect nugget: Amiodarone can make the defibrillation threshold higher in some cases, that is, harder to get the heart to defibrillate. But since it stabilizes the rhythm, we don't worry too much about this when dealing with a sick heart. If the heart keeps going into Vfib, we fix everything we can (acid–base, electrolytes, coronary perfusion pressure, and temperature) and we keep giving amiodarone until the heart behaves. In some cases, because we are dealing with sick hearts, mechanical support is instituted, such as in an intraaortic balloon pump.
- Contraindications to amiodarone include severe sinus node dysfunction with marked sinus bradycardia or syncope, second- or third-degree heart block, known hypersensitivity to its contents, cardiogenic shock, and probably severe chronic lung disease.
- Multiple administration of intravenous amiodarone boluses may lead to the delayed appearance of an ARDS-like syndrome due to the pulmonary deposition of this agent as well as its known pulmonary toxicity.
- Amiodarone is a paninhibitor of the cytochrome P450 enzymes. As such, it is metabolically very active and will interact with a variety of drugs including coumadin, digoxin, metoprolol, phenytoin, amitriptyline, and cyclosporine.
- The treatment of AFIB with ibutilide, dofetilide, or sotalol should be done in

consultation with a cardiologist experienced and qualified to administer these drugs.

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# Ondansetron Is a Great Drug, We ALL Use It, But Watch for Headache and QT Prolongation

Catherine Marcucci, MD and Michael J. Moritz, MD FACS

Ondansetron (Zofran) is a 5-HT3 receptor antagonist that came into clinical use in the mid-1980s. It one of the most widely used antiemetic agents in current clinical practice to combat the distressing symptoms of postoperative nausea and vomiting (PONV).

The four 5-HT3 antagonist drugs available in the United States are ondansetron (Zofran), granisetron (Kytril), dolasetron (Anzemet), and palonosetron (Aloxi). These 5-HT3 receptor antagonists are the most effective antiemetic drugs available. The individual 5-HT3 antagonists are dissimilar in structure and metabolic profile, but all three drugs are similar in effectiveness, cost, and side-effect profiles.

## Serotonin Pharmacology and the Antiemetic Effect

Serotonin, or 5-hydroxytryptamine (5-HT), is a neurotransmitter derived from the amino acid tryptophan. Systemic 5-HT affects the cardiovascular, respiratory, and gastrointestinal systems, with vasoconstriction being the typical vascular response. Thus, 5-HT antagonists will cause vasodilation. In the gastrointestinal system, most serotonin receptors are of the 5-HT3 type. The strongest stimulus for emesis from both chemotherapy and postoperatively is serotonin release from the gut enterochromaffin cells. This release stimulates afferent vagal fibers via their 5-HT3 receptors that activate the vomiting center in the brainstem (chemoreceptor trigger zone). Thus, serotonin antagonists decrease nausea and cause vasodilation.

## Other Indications

There is recently published information suggesting an adjunctive role for ondansetron in intravenous regional anesthesia (IVRA) which is also known as the Bier block. This technique is not in use at our institutions at present, but it is an intriguing idea. It seeks to capitalize on the anti-inflammatory and anesthetic effects of ondansetron and the antagonism of serotonin's role in the transmission of nociceptive pain. Several studies have also suggested that ondansetron can significantly reduce pain on injection of both

propofol and rocuronium.

## Overall Safety Profile

The 5-HT3 antagonists have relatively few side effects and are generally considered to be a great improvement over the previous class of antiemetics such as phenothiazines. They have virtually no activity at the dopamine receptor. They do not cause sedation or extrapyramidal side effects. Ondansetron is extensively metabolized by the family of liver cytochrome (CYP) P450 enzymes and is a substrate of CYP1A, CYP3A, and CYP2D6. It does not appear to act either as CYP450 inhibitor or inducer. In every day terms, this means that ondansetron will not "mess up" (i.e., increase or decrease) the blood levels of coadministered medications. Rather, it is more likely to be a "victim" of drug–drug interactions and have its own metabolism and serum drug levels inhibited or induced.

Although the 5-HT3 blockers including ondansetron are generally well tolerated, there are several associated effects that should be noted by clinicians who administer it on a frequent basis.

## Headache

The most common side effect is headache, occurring in 10% to 20% of patients receiving doses to prevent chemotherapy-induced emesis and in 10% of patients receiving the lower doses used for postoperative nausea and vomiting. In children in particular, a personal or family history of migraine headache leads to a much higher risk of ondansetron-related migraine at the antiemetic dosing for chemotherapy.

The interplay of the 5-HT3 receptor, vasodilation, and vasoconstriction can be seen in the management of migraine. The treatment of migraine blocks the vasodilation that causes the headache, typically with serotonin agonists. For example, sumatriptan succinate (Imitrex) is a 5-HT1 agonist that causes vasoconstriction. Because the 5-HT3 antagonists cause vasodilation, their use should be considered carefully in patients susceptible to migraines, especially children.

Interestingly, it has been suggested that ondansetron might have an ameliorating effect on headaches that are not primarily caused by a vasodilatory mechanism. A recent double-blind randomized, placebo-controlled study suggested that pretreatment with 0.15 mg/kg ondansetron versus saline resulted in a significantly lower incidence of postdural puncture headache in women undergoing cesarean section delivery under spinal anesthesia.

## ECG Effects—QTc Prolongation

Ondansetron acts to block both sodium and potassium channels in cardiac tissue. It has long been recognized that ondansetron and the other 5HT3 antagonists are associated with multiple ECG changes. Of these, prolongation of the QTc interval is of some concern and is understood to be dose dependent. In 2012, the Food and Drug Administration issued an advisory warning against administering a single 32-mg dose and notified the public that is was removing the approval of that dose from the drug label. A recently completed study had suggested that this dose would pose a risk of clinically relevant QT prolongation leading to torsade de pointes. The advisory did not change the recommended lower dose of 0.15 mg/kg every 3 hours.

A number of studies have not found the QT prolongation associated with ondansetron to result in statistical increases in the occurrence of torsades de pointes. It is important to keep in mind that these studies generally involve healthy volunteers without the compounding effect of multiple agents that prolong the QT interval. The FDA Advisory further states, "Patients who may be at risk for QT prolongation with ondansetron are those with congenital long QT syndrome, congestive heart failure, bradyarrhythmias, or patients taking concomitant medications that prolong the QT interval." There are many drugs that prolong QT interval—some common ones are propofol, sevoflurane, amiodarone, ciprofloxacin, cocaine, droperidol, famotidine, lansoprazole, omeprazole, methadone, piperacillin/tazobactam (Zosyn), ritonavir, tacrolimus, tamoxifen, and psychiatric medications such as amitriptyline, aripiprazole, clozapine, and lithium.

In addition, ondansetron, even at a lower dose, should be given cautiously in the presence of significant electrolyte abnormalities such as hypokalemia or hypomagnesemia, especially if the patient is symptomatic.

## TAKE HOME POINTS

- Ondansetron is a 5-HT3 antagonist in everyday use as a perioperative antiemetic agent.
- The strongest stimulus for emesis from both chemotherapy and postoperatively is serotonin release from the gut enterochromaffin cells.
- In the gastrointestinal system, most serotonin receptors are of the 5-HT3 subtype.
- Serotonin has multiple systemic effects; the most typical vascular response is vasoconstriction.
- The use of ondansetron as an adjunctive anesthetic in intravascular regional anesthesia (Bier block) to potentiate the anesthetic effects of lidocaine and decrease tourniquet pain is being explored in the literature.
- Several studies have suggested that ondansetron decreases injection pain for propofol and rocuronium.
- Ondansetron is a CYP1A, CYP3A, and CYP2D6 substrate. It does not appear to act

as an inducer or inhibitor for the cytochrome P450 family of liver enzymes.

- The 5-HT3 antagonists generally have relatively few side effects; however, anesthesia providers should be aware of the interplay of the 5-HT3 receptor and vasodilation, as it plays a role in the pathogenesis of migraine-type headaches, especially in children.
- Clinicians should be aware that ondansetron is associated with lengthening of the QT interval and torsade de pointes has been reported. Caution should be exercised when given to patients with electrolyte depletion, pre-existing cardiac conditions such as congenital long QT syndrome, and coadministration with other QT-prolonging drugs.

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# A Word About Haloperidol in the Perioperative Period

Neil B. Sandson, MD

As a consultation-liaison psychiatrist, I am frequently asked about the use of haloperidol (Haldol) in the perioperative period. Haldol is a fairly simple and straightforward drug that has been in clinical use for many decades. Nonetheless, some confusion remains.

Haloperidol is a butyrophenone compound that is known as a "typical" antipsychotic. It was developed in 1958 and is considered one of the essential drugs for public health by the World Health Organization. It can be administered via oral, intravenous, or intramuscular routes. A long-acting form of the drug (Haldol Decanoate) is also commonly given to ensure treatment compliance. It is sometimes referred to colloquially as a "major tranquilizer."

## Basic Pharmacology and Pharmacokinetics

Haloperidol is a dopamine receptor antagonist. It is effective at quelling agitation due its strong blockade of dopamine subtype 2 (D-2) receptors. However, unlike some other typical antipsychotics, haloperidol is a much less avid blocker of the muscarinic and alpha-1 receptors, leading to fewer anticholinergic symptoms and less orthostasis. This relatively clean postsynaptic receptor occupancy profile makes haloperidol a useful choice to address agitation in the context of dementia and delirium. While haloperidol has a somewhat greater tendency to prolong the QTc interval than most of the other antipsychotic drugs (more on this below), these advantages explain why haloperidol is the most frequently used of the antipsychotic drugs on a PRN basis.

## Risks and Side Effects

First, as is true of all meaningful D-2 antagonists, haloperidol can produce significant extrapyramidal symptoms (EPS). Acute forms of EPS include Parkinsonism, acute dystonic reactions, and akathisia. The first two of these can be addressed by adding anticholinergic drugs like benztropine (Cogentin) or diphenhydramine (Benadryl), but in doing so, one forfeits the advantage of haloperidol's lesser anticholinergic profile.

Akathisia is best addressed through use of beta-blockers, most notably propranolol. The major sub-acute form of EPS is tardive dyskinesia, characterized by a variety of choreo-athetoid movements. This syndrome tends to arise only with long-term use of high-dosage haloperidol and thus is not of immediate relevance to those who administer anesthesia. EPS is generally dosage-dependent, and thus judicious dosing will often avoid these difficulties.

Second, as with other butyrophenones, haloperidol can meaningfully increase the QTc interval. The package insert for haloperidol has a "black box" warning related to its arrhythmogenic potential. One could write an entire book devoted to the nuances of QT prolongation, but suffice it to say that haloperidol has moderate capabilities in this regard. When providing haloperidol, it is therefore prudent to review other medications in a given patient's regimen to ensure that haloperidol does not produce a synergistic effect with other QT prolongers (a pharmacodynamic drug–drug interaction), as well as closely monitor electrolytes and take other reasonable measures to address this potential concern. Fortunately, questions about whether patients can safely tolerate haloperidol can be quickly resolved by use of electrocardiograms and/or cardiac monitoring. So long as the QTc is on the happy side of 500 milliseconds, there should not be a problem. In light of the greater potential for intravenous haloperidol to produce QTc prolongation, it is considered a tenet of the standard of care that all patients receiving intravenous haloperidol need to be observed on telemetry for the duration of that exposure.

## Pharmacokinetics

On the pharmacokinetic end, haloperidol is metabolized primarily by cytochrome P450 3A4 and as yet poorly characterized Phase II enzymes, with secondary contributions from P450 2D6 and 1A2. These multiple metabolic pathways mean that only enzymatic pan-inhibitors, such as fluoxetine (Prozac), are likely to meaningfully increase haloperidol blood levels, thus increasing the probability of a patient experiencing EPS and other side-effects. However, a variety of enzymatic inducers of one or more enzymes (tobacco smoking at 1A2; carbamazepine at 1A2, 3A4, and Phase II; phenytoin at 3A4 and phase II; etc.) can meaningfully decrease haloperidol levels, possibly diminishing therapeutic efficacy. One of haloperidol's metabolites is a relatively potent 2D6 inhibitor, and haloperidol is also a P-glycoprotein inhibitor, but from a practical clinical perspective, haloperidol is seldom a pharmacokinetic "culprit" implicated in strongly raising blood levels of other drugs.

## Haloperidol Clinical Pearls for the Anesthesiologist

Anesthesiologists will "encounter" haloperidol in the perioperative period in one of

two ways—either as a chronic medication in a preoperative medication regimen or when given in one or repeated PRN doses for acute agitation. The most important message that I want to convey is that both situations are relatively straightforward if you keep the basic pharmacology and specifically pharmacokinetics in mind. Haloperidol is NOT one of the psychoactive drugs that has the potential to cause significant morbidity in the perioperative period such as the monoamine oxidase inhibitors (MAOIs) or lithium. It suffers from something of a cultural misperception. It dates from the "dark ages" of psychopharmacology and in the early days was not always administered with Cogentin. I have received a number of calls from anesthesiologists (including Cathy Marcucci) concerned about either pharmacodynamic or pharmacokinetic interactions. Since I consider myself something of an honorary anesthesiologist at this point, here are some helpful hints.

**Patients on standing haloperidol doses:** Let us say you are looking at your patients for the next day and you sit down and click open the electronic chart and the first thing that pops out at you on the patient's medication list is haloperidol, 10 mg PO every evening.

What are your questions to yourself with respect to the Haldol?

) Why is the patient being treated for behavioral dyscontrol and/or psychosis? Do they have a diagnosis of schizophrenia? If they do, then remember the clinical ramifications of that very serious disease, such as high incidence of obstructive sleep apnea, poor self-care, and so forth.

) Does the patient have both competency and capacity to give consent? Remember that these are not the same! Competency is the legal determination that a patient generally has the potential ability to manage their own affairs, whereas capacity relates to specific ability to weigh risks and benefits and make rational decisions pertaining to specific health care choices. Competency is determined by a judge and the default mode is that until a judge has determined otherwise, everyone is competent. Capacity is determined by clinicians and relies on discrete determinations for each and every decision; there is no true default mode.

) What is the QTc interval? Is the patient on any other QT-prolonging drugs? Will you be aware of the haloperidol QT interval effect if the patient is started on a drug such as amiodarone?

) Has the patient habituated to the sedating effects of the haloperidol? After all, this drug is one of the "major tranquilizers." It is generally given at night because of its sedative nature—what might be the additive effect of haloperidol and the sedating

nature of anesthetics and opioids in the perioperative period?

) Will haloperidol cause any disruptions in the blood levels of any other important perioperative agents? No. It is more a victim in drug–drug interactions than a perpetrator.

) Assuming the patient is not suffering from oversedation, should the haloperidol just be continued in the standing dose throughout the perioperative period? Yes

') Is a missed dose a problem? **No.**

**Patients who receive PRN haloperidol doses as inpatients:** Now let us say you are working in the ICU or doing an inpatient preoperative evaluation and you see that the patient has received multiple PRN haloperidol doses. Or you are writing orders and maybe you think the patient might need PRN dosing. What is your thought process?

) Is this patient already on a standing haloperidol dose? If so, acute agitation and/or delirium should be investigated for a medical etiology. In my experience it is unusual for an acute hospitalized patient on a standing haloperidol dose to be a brisk responder to additional PRN haloperidol.

) Is your patient withdrawing from alcohol or another central nervous system depressant? If so, it is imperative that you treat that immediately, and NOT with haloperidol.

) Does this represent a symptom or exacerbation of posttraumatic stress disorder (PTSD)? If so, I would generally treat those patients with a benzodiazepine, typically lorazepam 0.5 to 2 mg, either by mouth, via intramuscular injection, or intravenously. PTSD is an anxiety disorder and is better treated with anxiolysis instead of an antipsychotic.

·) How old is the patient? For young adults, up to 5 mg haloperidol, either by mouth, via intramuscular injection, or intravenously can be given. For adults over the age of 65, a typical dose of haloperidol is 2 mg. In the elderly, the PRN haloperidol dose is even lower, anywhere from 0.25 to 1 mg. Of note, a section of the black box warning for haloperidol reads “Elderly patients with dementia-related psychosis treated with antipsychotic drugs are at increased risk of death.” Haloperidol’s arrhythmogenic potential means that this warning applies to haloperidol somewhat more pointedly than most of its fellow antipsychotics. However, this warning really relates to chronic

and consistent exposures, generally standing dosing, rather than relatively occasional PRN dosing.

) Haloperidol, when given in small PRN doses, generally does not prolong the QT interval or produce anticholinergic symptoms.

) If your patient is requiring more than two PRN doses of haloperidol in a day, it is time to call your friends, the psychiatrists.

) Keep in mind that any time you medicate a delirious patient's agitation, you are potentially further clouding their already altered mental status. In the short term, the patient's behavioral dyscontrol will diminish, but the underlying mental derangement will not be resolved by this maneuver, and it may even be exacerbated by it.

## TAKE HOME POINTS

- Psychiatric drugs remain something of a mystery to perioperative providers.
- Haloperidol is a first-generation antipsychotic drug that is still in widespread use.
- Patients on haloperidol as a standing medication should raise the clinical concern of schizophrenia or other major psychotic disorders.
- In the preoperative period, the presence of haloperidol in the medication list mandates attention to the ability of the patient to give consent and the QT interval.
- Haloperidol can generally be safely given as PRN doses to patients who are experiencing acute behavioral dyscontrol, even patients who are medically complex. Dosing should be age-adjusted.

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# Remember That Not All Blue-Colored Compounds Are the Same

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There are many blue dye compounds, and each is used for a variety of purposes. Their uses include food coloring, dye for materials, antiseptics, tissue stains, chemical reaction indicators, and to treat diseased aquarium life. Blue dyes are also used in humans for both diagnostic and therapeutic purposes. These dyes include methylene blue, patent blue, isosulfan blue, and indigo carmine. While these substances are all blue in color, they are distinct compounds and have widely varying properties, uses, and adverse effects.

## Methylene Blue

**Synonyms:** Methylthioninium chloride, tetramethylthionine chloride, urolene blue, swiss blue, solvent blue

Methylene blue has been used in many clinical situations in humans. It is used primarily as an antidote for both chronic methemoglobinemia (e.g., occurring with dapsone therapy) and acute methemoglobinemia (e.g., 20% oral topical benzocaine spray). At low concentrations it promotes the reduction of methemoglobin (the ferric form of hemoglobin) to hemoglobin by acting as a cofactor for the enzyme NADPH-methemoglobin reductase. The recommended dose is 1 to 2 mg/kg administered intravenously (IV). The dose may be repeated after 1 hour if symptoms persist.

Methylene blue has been used as a sentinel lymph node tracer for breast cancer and may be as efficacious and have fewer side effects than other blue dyes more traditionally used for this purpose. It has been used in the past as a genitourinary antiseptic and the therapy of cyanide poisoning although these uses are no longer recommended. Cyanide poisoning therapy with hydroxocobalamin is the preferred antidote.

Since methylene blue has monoamine oxidase inhibition properties, serotonergic syndrome may occur when used concomitantly with drugs that increase serotonin. These would include, but are not limited to, selective serotonin reuptake inhibitors (SSRIs),

serotonin norepinephrine reuptake inhibitors (SNRIs), and monoamine oxidase inhibitors (MAOIs). There is a black box warning on concomitant use provided by the manufacturer. Possible additional adverse effects of methylene blue include chest pain; headache; confusion; dizziness; diaphoresis; anemia; discoloration of skin, urine, and feces; nausea; vomiting; abdominal pain; and bladder irritation.

An additional adverse effect is an increase in blood pressure. Although this may be unwanted in some cases, methylene blue has been used "off label" to treat vasoplegia. Methylene blue appears to inhibit cyclic guanosine monophosphate resulting in vasoconstriction and improvement in refractory hypotension caused by multiple inflammatory mediators.

Methylene blue can also transiently decrease pulse oximetry readings by causing the oximeter to interpret methylene blue as deoxygenated blood. It is sometimes used by anesthesia personnel as an indicator dye or "marker" to denote a special situation in the operating room, such as an IV bag that has had succinylcholine added to it or to provide a visual cue to diagnose an endotracheal cuff leak. Be aware, however, that the high side-effect profile of methylene blue mandates careful consideration of this type of use.

## Patent Blue

**Synonyms**: Sulfan blue, blue v, disulfine blue, food blue 5

In humans, patent blue is used primarily for lymphangiography and sentinel node biopsy. When a tumor is identified, dye is injected into the tumor and peritumoral tissue. The dye is then taken up by the lymphatics that drain that region. The first lymph node that absorbs dye is the sentinel lymph node. This node is then biopsied and checked for malignancy. This information is used for staging, to decide whether more extensive lymph node dissection is needed, and to determine the need for other adjuvant therapies. This modality is most commonly used in breast cancer, but is also used for other cancers, such as melanoma, endometrial cancer, and colon cancer. Before the development of sentinel node biopsies, radical lymph node dissections were routinely performed for breast cancer. Patent blue can also be used in conjunction with radiolabeled materials as an alternative method of identifying sentinel nodes.

The side-effect profile of patent blue is of considerable concern to users. It has been cited as causing severe anaphylaxis in humans and its use is limited in certain countries, including the United States. In addition, pulse oximetry readings can be artificially reduced for prolonged periods with higher doses of patent blue. This is likely because the dye is being injected subcutaneously versus intravascularly as with methylene blue.

## Isosulfan Blue

Isosulfan blue (also called lymphazurin) is the 2,5-disulfophenyl isomer of patent (or

sulfan) blue and is also used for tumor marking and lymphangiography for sentinel node biopsies.

Though it is generally thought to be safer than sulfan blue, it has been cited as causing an array of allergic reactions ranging from mild urticaria to severe life-threatening anaphylaxis. These reactions are more likely in individuals with a history of asthma or other allergies and it is recommended to monitor the patient for at least 60 minutes following administration. Preoperative prophylaxis appears to reduce the severity but not the incidence of these reactions. Isosulfan blue has similar affects as patent blue on transiently decreasing pulse oximetry readings. It should not be mixed in the same syringe with local anesthetics as this will result in immediate precipitation.

## Indigo Carmine

**Synonyms:** Sodium indigotindisulfonate, soluble indigo blue, indigotine, Acid Blue 74, FD&C Blue No. 2

Indigo carmine is excreted unaltered by the kidneys. This excretion is relatively fast, and blue urine can be seen as quickly as 5 to 10 minutes after administration. It was once used as a kidney test to rule out obstruction before more sophisticated modalities became available. It is currently used to locate ureteral orifices during cystoscopy, to test cystourethral anastomosis, and to identify transected ureters intraoperatively. Typically, a 5-mL one-time dose of indigo carmine is administered intravenously.

This compound has a relatively low side-effect profile; however, elevations in both systolic and diastolic blood pressure have been reported. Indigo carmine can cause a transient decrease in pulse oximetry readings.

## Indocyanine Green

**Synonyms:** Fox Green, Cardio-Green

Despite its name, indocyanine green is often grouped with the blue dyes. In humans, indocyanine green is most commonly used for eye surgery, specifically for macular hole and cataract surgery. It can be toxic to the eye if not thoroughly removed at the end of surgery. Its tissue-toxic effects have been used for therapeutic purposes in the photo-oxidative destruction of colon cancer cells with infrared light. It can also be used as a diagnostic aid in blood volume determination and cardiac output via its absorption properties. Indocyanine green may cause a transient decrease in pulse oximetry if it is injected intravascularly.

## FDA Public Health Advisory!

In September 2003, the U.S. Food and Drug Administration (FDA) issued a Public

Health Advisory against the use of blue dye to color enteral feeds as a means to detect pulmonary aspiration. Though this practice had been in effect for about 30 years, it had been previously uninvestigated by the FDA. The report specifically targets FD&C Blue No. 1, which is used in much lower concentrations in foods, cosmetics, and drugs. This compound is also known as Blue #1 and Steri-Blue. Blue #1 was temporally associated with several effects. These included discoloration of skin, urine, feces, serum, refractory hypotension, metabolic acidosis, and death. The most susceptible patient population was the critically ill and those with increased gut permeability (i.e., patients with sepsis, trauma, burns, and inflammatory bowel disease). The exact reason for severe side effects is not known, but Blue No. 1 is known to be a mitochondrial toxin, which could lead to severe metabolic acidosis. Finally, the FDA states that other blue dyes such as methylene blue and FD&C Blue No. 2 (indigo carmine) may have similar or even worse toxicity than Blue No. 1 and are not appropriate replacements. Some experienced hospital pharmacists are now recommending that the above-described blue dyes not be used when contact with the gastrointestinal tract is possible.

## TAKE HOME POINTS

- These compounds are all blue in color, but they have a wide variety of properties.
- Most blue compounds can affect pulse oximetry readings.
- Methylene blue has a high side-effect profile (e.g., hypertension) and drug–drug interactions (e.g., SSRIs).
- Patent blue can cause severe anaphylaxis in humans.
- Preoperative prophylaxis can reduce the severity of reactions seen with isosulfan blue.
- Indigo carmine has a relatively low side-effect profile.
- Indocyanine green must be thoroughly washed out after eye surgery.
- Blue compounds should not be used as markers in enteral feeds.

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# Clonidine Considerations

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Originally introduced clinically as a nasal decongestant and subsequently used as a centrally acting antihypertensive, clonidine has become increasingly utilized for its anesthetic properties. The sedative effects of alpha-2 agonists have been known since their introduction. In fact, a volunteer once slept for an entire day following a dose of intranasal clonidine. Human and animal studies performed in the late 1960s demonstrated a profound reduction in MAC when inhalation agents were administered concurrently with alpha-2 receptor agonists such as clonidine. Alpha-receptor agonists have been utilized in veterinary medicine for many years as a regional anesthetic, but only relatively recently have they been employed in humans. Tamsen and Gordh injected a parenteral preparation of clonidine epidurally into two patients in 1984 after they first established its safety in animals. Since that time a large body of research has explored both the safety and clinical benefits of clonidine as an analgesic; however, it is only FDA approved to treat hypertension and in the treatment of cancer pain. Though more popular in Europe, clonidine is used off label in the United States for many other benefits. At the time of introduction of dexmedetomidine, it was surmised that clonidine would fall out of clinical use and cease to be of interest to investigators. However, the literature has continued to furnish clinicians with updated information on the dosing and efficacy of clonidine in a variety of clinical situations.

## Chemical Properties/Pharmacology

Clonidine, an imidazoline, is a partial alpha-2 adrenergic receptor agonist that primarily acts presynaptically and inhibits norepinephrine release in the nucleus tractus solitarii of the medulla oblongata. It is not highly selective at alpha-receptors as it has a selectivity ratio of approximately 200:1 for alpha-2 to alpha-1 receptors, respectively; dexmedetomidine's selectivity is ~1,600:1. Furthermore, clonidine is able to interact with noradrenergic imidazoline receptors found in the brain, kidney, and pancreas. Alpha-2 adrenergic receptors function through G-protein mechanisms. Four subtypes exist and all activate well-defined intracellular cascades. Clonidine was first thought to

exhibit its effects primarily through presynaptic receptors in the medulla, though it is now known to also act both directly in spinal preganglionic sympathetic neurons as well as in the dorsal horn by pre- and postsynaptic mechanisms.

## Physiologic Effects

The primary effect of clonidine is sympatholytic, but possibly due to the fact that it binds with many different receptors the drug has a variety of different actions beyond antihypertensive properties such as sedation, anxiolysis, analgesia, and as an adjunct with other anesthetics. Clonidine decreases central sympathetic outflow thereby lowering arterial pressure. At low doses, clonidine has an anxiolytic effect on the CNS, though at higher doses it can be anxiogenic and cause hypertension most likely due to alpha-1 activity. Little effect is exerted on the respiratory system, save a small reduction in minute ventilation. Alpha-2 receptors of beta cells in the pancreas are stimulated and cause a temporary inhibition of insulin release. This has not been proven to be problematic in a clinical setting. Clonidine has the added benefit for anesthesia of an antisialagogue effect. Clonidine overdose, either intentional or accidental, causes prolonged bradycardia and central nervous system depression but generally is not fatal or even severely toxic.

## Dosing/Duration of Action

The high lipid solubility of clonidine allows rapid and complete absorption after oral administration. Less than 50 percent is metabolized hepatically to inactive metabolites with the remaining drug excreted unchanged by the kidneys. Orally, the peak plasma level is reached in 1 to 1.5 hours. It readily crosses the blood–brain barrier with the elimination half-life of 30 minutes after epidural injection of 150 µg. In general, hemodynamic effects peak around 1 to 2 hours and last approximately 6 to 8 hours. Sedation occurs in a dose-dependent fashion within 20 minutes regardless of the route of administration. These effects can last 4 to 6 hours.

Dosing information on clonidine is shown below:

**For Hypertension**

**Oral (adults):** Initially, 0.1 mg PO twice daily; increase by 0.1 to 0.2 mg/day PO until desired effect is achieved (usual dosage range: 0.2 to 0.6 mg/day PO).

**Children:** Initially, 5 to 10 µg/kg/day PO in divided doses every 8 to 12 hours. Increase gradually (every 5 to 7 days) to 5 to 25 µg/kg/day PO in divided doses every 6 hours. Maximum dosage is 0.9 mg/day.

**Transdermal (adults only):** Initially, apply one patch (delivers 0.1 mg/24 hours) patch to an intact area of hairless skin on the upper arm or torso, once every 7 days. Adjust dosage every 1 to 2 weeks.

### Neuraxial Pain Control

**Adults:** Initially, 30 µg/hour by continuous epidural infusion in combination with opioid analgesics. Dosage titration is based on pain relief and adverse events, the maximum rate of 40 µg/hour. In clinical trials, bolus doses of epidural clonidine range from 100 to 900 µg per dose.

Intrathecal clonidine in dose of 25 to 40 µg/hour (600 to 960 µg/day) has been used to manage chronic pain patients.

### Pediatric Anesthesia Usage

Given orally preoperatively (4 µg/kg), decreases intraoperative anesthetic requirements and postoperative opioid consumption.

The epidural or caudal dose is 1 to 2 µg/kg, which may be followed by an infusion of 0.05 to 0.33 µg/kg/hour. It may cause sedation and hypotension when given via epidural route.

### Regional Anesthesia

Dose 0.5 µg/kg or greater, enhances and prolongs the effect of local anesthetics used for brachial plexus block, peribulbar and retrobulbar blocks, and IV regional anesthesia.

An intra-articular dose of 150 µg enhanced postoperative analgesia in patients undergoing knee arthroscopy. Hemodynamic effects, namely bradycardia and hypotension, increase with doses of 1.5 µg/kg or more.

## Antihypertensive and Cardiovascular Effects

Hypertensive patients usually respond to clonidine with a more profound drop in blood pressure than do normotensive patients. Though clonidine reduces heart rate it seems to have little effect on the baroreceptor reflex, thus accompanying orthostatic hypotension and profound bradycardia are produced less frequently than with other antihypertensive drugs. Researchers have shown an attenuation of the stress response to direct laryngoscopy when a minimum dose of 4 µg/kg clonidine is administered IV preoperatively. Although some studies have shown a possible benefit in reducing perioperative cardiac ischemia, the POISE-2 Trial determined that “low-dose clonidine in patients undergoing noncardiac surgery did not reduce the rate of the composite outcome of death or nonfatal myocardial infarction; it did, however, increase the risk of

clinically important hypotension and nonfatal cardiac arrest." A 2017 study by Tosh et al. demonstrated that oral clonidine premedication attenuated the hemodynamic responses of ketamine during total intravenous anesthesia (TIVA). We personally have found that a low-dose clonidine patch applied at the time the patient is checked in for carotid endarterectomy results in smoother intraoperative and postoperative hemodynamics. However, perioperative clinicians should always be mindful that rapid discontinuation of clonidine can precipitate a hypertensive crisis and clonidine should be dosed throughout the perioperative period.

## Sedation/Reduction in Anesthetic Requirements

Although clonidine is not used as a sole anesthetic agent, it has been used as a premedication in numerous studies. It is especially useful in pediatrics. In comparison to benzodiazepines, clonidine produces a state of sedation similar to sleepiness rather than amnesia—much like its brother dexmedetomidine. Subjects are more easily roused when asked to perform tasks. Clonidine has also been shown to be an effective anxiolytic. A reduction in halothane MAC by as much as 50% has been demonstrated experimentally with clonidine. This effect has largely been demonstrated clinically with other inhaled anesthetics. Other studies have demonstrated reductions in opioid, benzodiazepine, barbiturate, and propofol requirements.

## Analgesia

Oral, epidural, intrathecal, and parenteral administration of clonidine—all produce analgesia and potentiate the action of other agents, thus enhancing motor and sensory blockade. This corresponds to a reduced side-effect profile in most instances. Epidural administration is most common, as a number of studies have demonstrated epidural clonidine to be an efficacious adjunct to opioid and local anesthetic injection in the management of acute postoperative pain or may even replace the opioid altogether. Studies have also demonstrated epidural clonidine to be superior to intravenous use for pain control after orthopedic surgery. Previously it was thought that there was little incentive for the use of intrathecal clonidine in that intrathecal clonidine did not provide additional benefit to epidural clonidine as it provides no additional analgesia. However, recent studies have served to establish that there is a definite analgesic effect to intrathecal clonidine, even compared to other intrathecal adjuncts. For example, a 2017 study showed that 50 μg added to 2.5 mL of hyperbaric bupivacaine was superior to fentanyl 25 μg added to an identical fentanyl dose with respect to time to first dose of rescue analgesic and duration of sensory and motor block and provided greater intraoperative sedation in lower-extremity orthopedic procedures. A meta-analysis concluded that intrathecal clonidine improved analgesia without impacting neonatal

arterial pH or Apgar scores.

Also popular for use as an adjunct in regional anesthesia, clonidine prolongs duration of peripheral nerve blocks at small doses, but does run the risk of prolonging motor blockade. In recent years there has been some accumulation of data on the use of clonidine in field blocks. For example, clonidine added to a preincision bupivacaine field block resulted in better and prolonged postoperative analgesia in posterior spine surgery. Clonidine has also been shown to have efficacy as an adjuvant to local anesthetic infiltration and can prolong analgesia after episiotomy.

Chronic pain treatment with clonidine has several benefits including the avoidance of opioids in patients who may become dependent or addicted with long-term use. Clonidine is approved in the United States in the treatment of intractable cancer pain.

## Other Uses

Additional off label uses are particularly interesting to the anesthesiologist. Clonidine has been shown to decrease postoperative nausea and vomiting. It is an effective anti-sialagogue. Some studies have shown clonidine to be an efficacious alternative to meperidine for postoperative shivering. A decrease in intraocular pressure has been reported with the use of clonidine during ophthalmic surgery. Hyperactive children with manic symptoms have been treated with the drug. Clonidine has also been used in the treatment of opioid, benzodiazepine, and alcohol withdrawal as well in smoking cessation.

## Side Effects/Contraindications

Clonidine's side-effect profile makes it a useful adjunct in anesthesiology. Common side effects that are often desirable perioperatively include dry mouth and sedation. Abrupt discontinuation of clonidine can produce a withdrawal syndrome possibly resulting in nausea, insomnia, headaches, and restlessness. Severe sudden cessation can result in profound hypertension and tachycardia. As stated above, clonidine is a very mild respiratory depressant at indicated doses and does not appear to potentiate opioid-induced respiratory depression. In the event of an overdose, clonidine has been reported to act as a more significant respiratory depressant. Furthermore, in high doses alpha-1 activation can cause anxiety and therefore limits its use as a sedative. A recent retrospective study found that intentional clonidine overdose caused prolonged bradycardia and central nervous system depression but no fatalities or even severe systemic toxicity. However, one case report noted that a young patient who was using a specially compounded pain cream containing clonidine 0.2% for widespread neuropathic path suffered severely elevated serum clonidine levels along with altered mental status, bradycardia, hypertension, and subarachnoid hemorrhage.

Although it is well established that intrathecal or epidural administration of clonidine in not neurotoxic, these routes are not recommended in pregnancy as it can cause hypotension. Its safety in pregnancy, when given as an oral dose, has not been established. In the non-pregnant patient, clonidine has no absolute contraindications but should be avoided in patients with perioperative hypovolemia, spontaneous bradycardia, A–V block, and prolonged P–R intervals.

## TAKE HOME POINTS

- Clonidine serves as a useful drug to the anesthesiologist beyond its use as an antihypertensive.
- It is useful as a sedative, especially in pediatric anesthesia.
- Although it is not used as a sole anesthetic, clonidine reduced the dose requirements in epidural, intrathecal, peripheral, and field nerve blocks.
- Clonidine is approved for cancer pain and serves as an offlabel adjunct in the treatment of other chronic pain syndromes. It is also used in the treatment of opioid and nicotine withdrawal.
- Clonidine has additional benefits as an antisialagogue, antiemetic, and in reducing postoperative shivering.
- When the recommended dose is used, clonidine has very little side effects or contraindications, although toxicologists, compounding pharmacists, and chronic pain clinicians should be mindful of the anecdotal reports of the potential for toxicity with the use of topical clonidine preparations for neuropathic pain.

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# A Primer on the Psych Syndromes: Serotonin Syndrome Versus Neuroleptic Malignant Syndrome

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A 64-year-old man with unknown past medical history who had been living in the local YMCA was found down in his room and diagnosed with a subdural hematoma (SDH). He is not responsive, which is disproportional to the size of his SDH. His labs are remarkable for elevated BUN and creatinine—63 and 3.1, respectively. A urine drugs of abuse screen (UDAS) is negative. He is tachycardic and hypertensive with temperature of 39°C. Based on his neurologic examination, he is planned for a craniotomy with SDH evacuation. Despite induction with etomidate and a generous bolus of crystalloid, his blood pressure is labile throughout.

The critical care team and the surgeon are contributing the patient's symptoms to his SDH. Patients with unclear neuropsychologic history—a characteristic of the homeless—can present with odd manifestations of "basic" injuries, such as SDH. After the case, the social worker finds out that the patient had been taking someone else's medications. But what medications are the etiology? And what are you going to diagnose? And how are you going to treat it?

Underlying drug effects might exacerbate underlying pathologies or cause an improper diagnosis, especially in patients with altered mental status. Therefore, serotonin syndrome (SS) or neuroleptic malignant syndrome (NMS) must be in the differential diagnosis of patients who are having a difficult and stormy perioperative course, particularly if the patient is exhibiting tremors, clonus, agitation, and autonomic instability see Table 91.1. Unfortunately, we have found that there is considerable uncertainty about the physiology, causes, and course of both clinical situations. There is even considerable confusion and misuse of the names! For example, one major medical journal mistakenly used the term "malignant hyperthermia (MH)" instead of "neuroleptic malignant syndrome" as recently as 2017 in a discussion of the possible risks of a sudden withdrawal of dopamine replacement drugs.

The first thing to remember is that neither of these psychiatric syndromes has definitely been established to pose an increased risk for MH and vice versa. MH occurs predominantly in patients who have inherited a mutation of the ryanodine receptor found in skeletal muscle and is not associated with or linked to the dopamine receptor or excessive serotonergic activity in the central nervous system (CNS). There are clinical features between NMS and MH that call for increased vigilance but the studies to date have not established a firm link between the two.

**Table 91.1 ■ Comparison of Serotonin Syndrome and Neuroleptic Malignant Syndrome**

| | Serotonin Syndrome (SS) | Neuropathic Malignant Syndrome (NMS) |
|---|---|---|
| Symptom onset | Within 24 hours | Days to weeks |
| Neuromuscular reactivity | Hyper (myoclonus, tremor) | Delayed (bradyreflexia, rigidity) |
| Agents implicated | Serotonin agonist | Dopamine blocker |

## Serotonin Syndrome

- Can range from benign to life-threatening, fast onset
- Classic teaching is triad of symptoms (Fig. 91.1):
  - Mental status changes: anxiety, disorientation, agitated delirium, restlessness
  - Autonomic hyperactivity: tachycardia, diaphoresis, hyperthermia, hypertension, vomiting, diarrhea
  - Neuromuscular hyperactivity: hyperreflexia, myoclonus (lower extremities predominantly but not exclusively), bilateral Babinski sign, tremor, muscle rigidity
- Too much serotonergic activity in the CNS (Fig. 91.2) due to stimulation of 5-HT1A and 5-HT2A receptors
- Diagnosis is made based on history, clinical symptoms, vital signs, and physical examination
- Drugs implicated are selective serotonin reuptake inhibitors (SSRI), selective serotonin and norepinephrine reuptake inhibitors (SNRI), bupropion, trazodone, tertiary amine tricyclic antidepressants (TCA), ondansetron, metoclopramide, amphetamines, cocaine, MDMA, levodopa, monoamine oxidase inhibitors (**MAOIs**), Triptans, buspirone, fentanyl, lithium
- Treatment involves discontinuing all serotonergic meds (consider half-life), sedation

with benzodiazepines, supportive care (management of hypertension and hyperthermia), and watchful waiting in an intensive care setting. A serotonin antagonist (cyproheptadine) may be considered but does not have great and/or proven efficacy

## Neuroleptic Malignant Syndrome

- Life-threatening emergency (mortality 10% to 20%)
- Pathophysiology is not fully elucidated—one theory is dopamine receptor blockage in the hypothalamus and nigrostriatal pathways
- Clinical syndrome involves mental status change (agitated delirium), rigidity, dysautonomia (tachycardia, labile BP, tachypnea), and fever that evolves insidiously over days to weeks
- Diagnosis is made by history of administration of neuroleptic medication, high clinical suspicion, clinical symptoms, elevated CK

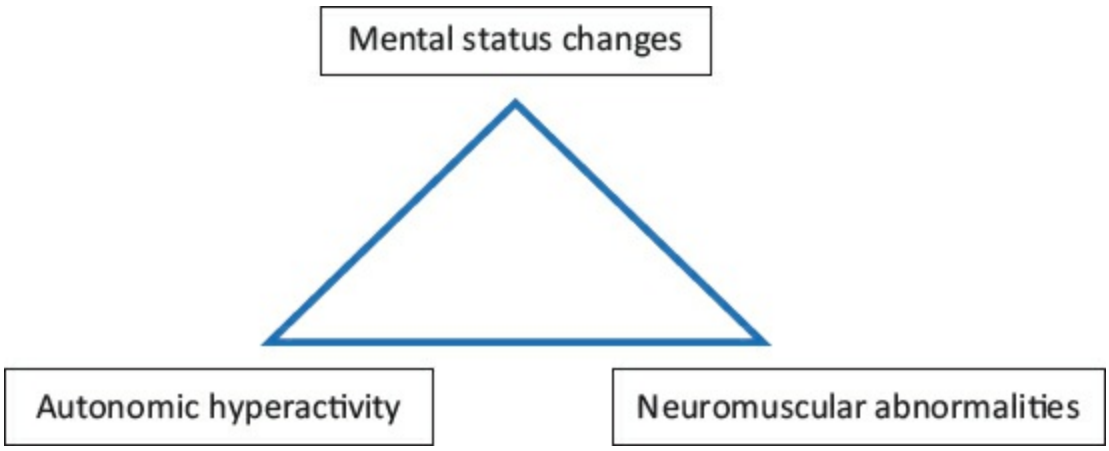


**Figure 91.1.** Serotonin Syndrome Symptom Triad.

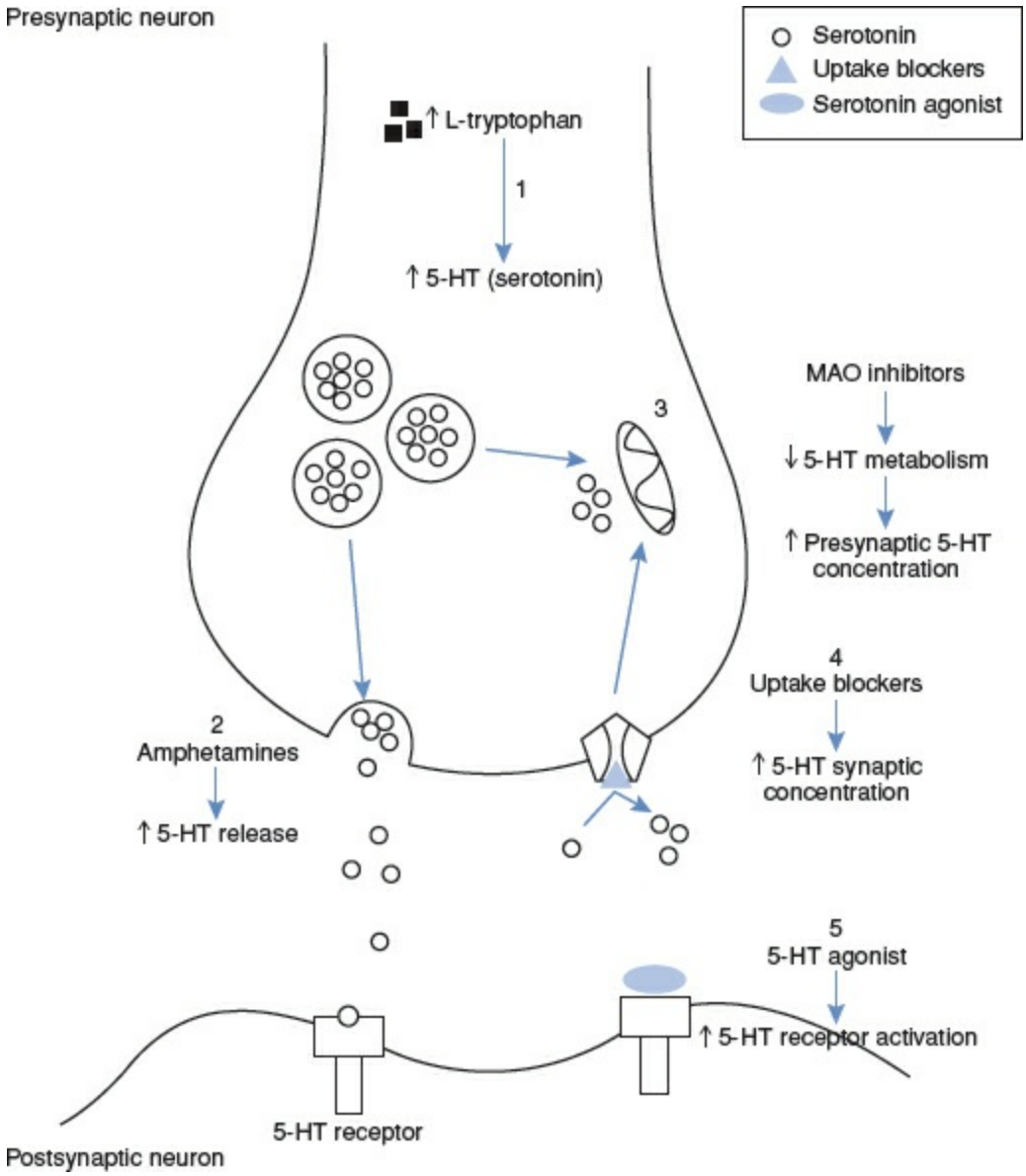


**Figure 91.2.** Neurophysiology of Serotonin Syndrome.

- Drugs implicated:
  - Neuroleptics: haloperidol, fluphenazine, chlorpromazine
  - Atypical antipsychotics: clozapine, risperidone, olanzapine
  - Antiemetics: metoclopramide, promethazine
  - Withdrawal from dopaminergic agents in Parkinsonian patients
- Treatment: discontinue inciting agent(s), supportive care, benzodiazepines, dantrolene, bromocriptine

## Serotonin Syndrome and Other Perioperative Drugs

Numerous cases of perioperative serotonin toxicity/syndrome have been reported in the literature. The first point made in the literature is that patients on serotonergic drugs call

for close vigilance and a high degree of suspicion in the preoperative evaluation. For example, one report described a patient on tramadol, trazodone, and duloxetine undergoing total colectomy. The patient's spouse reported that the patient had been experiencing occasional flushing, fevers, and diaphoresis in the 4 months prior to surgery but no additional investigation or workup was undertaken by the anesthesia providers. His intraoperative course was notable for repeated requests for additional neuromuscular blockade and prolonged emergence from anesthesia. His postoperative course was notable for tachycardia, ocular nystagmus, and significant upper- and lower-extremity muscle rigidity. He was diaphoretic, flushed, and agitated with masked facies, lip-smacking, and uncontrolled tongue movements as well as rhythmic myoclonic activity when attempting to grasp objects. The patient received an unplanned ICU stay and emergent imaging of his brain, which might have been avoided had he had the benefit of closer preoperative surveillance and adjustment of his serotonergic medications.

Fentanyl and methylene blue are especially worthy of mention with respect to SS. Fentanyl is a synthetic phenylpiperidine that has analgesic properties through its binding to mu receptors. However, it is also a 5-HT1A agonist which contributes to serotonin release. In addition, it acts as a weak serotonin reuptake inhibitor, which is a second mechanism that increases the levels of intrasynaptic serotonin. It is not considered to be a significant risk factor for SS as a solo pharmacologic agent (although at least one case report has documented this rare occurrence) but vigilance is required when fentanyl is administered to patients who are on medication regimens that include serotonergic agents, even when the fentanyl is given in standard perioperative doses.

Reports of SS occurring after administration of methylene blue in patients on psychiatric drugs are quite numerous. Remember that methylene blue is used as a marker dye and for treatment of methemoglobinemia and hypotensive shock. The chemical name for methylene blue is methylthioninium chloride. It is related to the tricyclic antidepressants and acts on the nitric oxide–cyclic GMP pathway and as a potent monoamine oxidase inhibitor, specifically for MAO-A.

Methylene blue, when administered as the sole serotonergic agent, is not generally considered to be a significant risk factor for SS. However, in combination with any other serotonergic agent, the risk is elevated. Thus, the perioperative provider must exercise vigilance with respect to serotonergic agents and include SS on their differential diagnosis decision tree at all times. Remember that the list of serotonergic agents includes the SSRIs such as fluoxetine, paroxetine, and escitalopram and the SNRIs such as venlafaxine and duloxetine as well as the "mild" serotonergic agents such as methadone, tramadol, meperidine, and intravenous and transdermal fentanyl. To complicate matters a bit, not all drugs in the same drug class pose the same risk of

serotonin toxicity to the patient. However, the FDA has issued a warning with respect to the coadministration of methylene blue and serotonergic drugs and recommends that all serotonergic drugs be discontinued prior to planned use of methylene blue in the intraoperative period. A review of methylene blue and the risk of serotonin toxicity in the June 2015 issue of the Anesthesia Patient Safety Foundation recommended a washout period of 2 weeks for most serotonergic drugs and drug metabolites in the absence of significant liver impairment. This publication noted that methylene blue may be given in life-threatening situations where the risk–benefit ratio warrants, such as for vasoplegia with cardiopulmonary bypass, methemoglobinemia, and cyanide poisoning, with monitoring for CNS symptoms for 24 hours after the last dose of methylene blue.

## Hunter Serotonin Toxicity Criteria

Historically, the diagnosis of SS was made by an experienced psycho-pharmacologist or medical toxicologist. However, public health initiatives aimed at the aggressive treatment of depression as well as pain syndromes mandated that more clinicians be able to make the clinical diagnosis, especially as there is no confirmatory laboratory test or pathognomonic diagnostic imaging for serotonin toxicity. Among the easiest to use and currently most widely accepted criteria are the Hunter Serotonin Toxicity Criteria, developed in Australia. The criteria are based on one of the most easily recognizable features of the syndrome, which is the presence of skeletal involvement, including tremors; akathisia; or spontaneous, inducible, or ocular clonus. Compared to the most experience and expert medical toxicologist, the Hunter criteria have a sensitivity and specificity of approximately 85% and 95%, respectively, even when employed by less-experienced clinicians.

To fulfill the Hunter Criteria, a patient must have taken a serotonergic agent or drug and exhibit one of the following:

- Spontaneous clonus
- Inducible clonus with agitation or diaphoresis
- Ocular clonus with agitation or diaphoresis
- Tremor with hyperreflexia
- Hypertonic state with elevated temperature (above 38°C) and ocular clonus or inducible clonus

## Neuroleptic Malignant Syndrome in the Perioperative Period

NMS may be seen both in the preoperative and postoperative period, as noted in the anesthesia literature. For example, there are reports of NMS occurring after withdrawal of anti-Parkinsonian drugs prior to coronary artery bypass grafting. Remember that in

the psychiatric community, there are clinicians and researchers who conceptualize NMS as a form of extreme Parkinsonian crisis. This is based on similar features of NMS and the Parkinsonian-hyperthermia syndrome that occurs with abrupt discontinuation of dopaminergic therapy, the fact that NMS-triggering drugs are dopamine receptor antagonists, and the efficacy of dopaminergic agonists as effective treatment.

Other predisposing factors for NMS in patients taking antipsychotic medications include malnutrition and/or dehydration, agitation stress, and additional administration of sedative drugs including haloperidol—all of which occur frequently in the perioperative period, of course, especially in complicated patients who have elevated baseline medical risks and poor underlying health status due to their psychiatric disease.

## So—What Is the Exact Mechanism for Neuroleptic Malignant Syndrome and Is It Related to Malignant Hyperthermia in Any Way?

Part of the problem in organizing our thinking about NMS is that the pathophysiology is complex, multifactorial, still not fully elucidated, and the varied onset and occurrence of NMS means that it is probably a family of syndromes. And of course, just to add to the confusion, it is a rare disease that mimics a large number of other syndromes and a number of other pathologies mimic it. In fact, as recently as 1988, NMS was also called "dopamine-dependent MH" in the academic literature.

What has been definitely established is that the primary trigger of NMS is dopamine receptor blockade and the "standard" causative agent is an antipsychotic such as haloperidol, fluphenazine, or chlorpromazine. The sudden reduction of D2 dopaminergic activity in the nigrostriatal, hypothalamic, and cortical/limbic systems partially explains the rigidity, hyperthermia, and mental status changes (respectively). There are also anecdotal reports of NMS occurring in the perioperative period in patients who are on stable antipsychotic medication dosing regimens, such as NMS seen after bilateral cemented total hip replacements or in the trauma and burn units. It is also not yet fully understood how and why the latency in NMS symptoms occurs and why NMS may not recur with repeat administration of the same or similar inciting dopamine-blocking medication. In fact, the majority of NMS patients are able to tolerate an antipsychotic neuroleptic medication at a subsequent point in their treatment.

However, it is now thought that the skeletal muscle system and the release of calcium from the sarcoplasmic reticulum (SR) also plays a role in the development of NMS, which is where some of the "crossover confusion" with MH has arisen. It has been suggested that antipsychotic medications can cause increased calcium release from the SR, leading to muscle breakdown, rigidity, and hyperthermia. Again, adding to the confusion, dantrolene is used in the treatment of both conditions.

The question of whether NMS and MH are each risk factors for the other syndrome has long dogged clinicians. The real question for anesthesiologists is whether patients who develop NMS are at increased risk for MH during anesthesia. Because these are both rare diseases, there are unfortunately no large case series. However, a 1995 review by Keck et al. examined studies that had been published since 1980, including the clinical features, risk factors, laboratory evaluations and summaries, and animal modes of both MNS and MH. They concluded, "Data from these studies suggest that although NMS and MH are clinically similar, they are pharmacologically distinct, implying that cross-reactivity between triggering agents is unlikely to occur." Several investigators have performed in vitro skeletal muscle caffeine contracture tests, looking for susceptibility to MH, in groups of known NMS patients and have found that the results were either negative or inconsistent and inconclusive. For example, in a small 1987 muscle contracture test study involving six patients in each study arm, Caroff et al. concluded that 5 of 7 NMS patients could be diagnosed as MH-susceptible, based on the development of muscle contracture greater than 0.7 g in response to 1% to 3% halothane. However, other authors do not agree. In 2000, Adnet et al. performed a similar in vitro halothane–caffeine contracture test on eight NMS, ten MH-susceptible, and ten control patients. This group defined the all eight NMS subjects as MH non-susceptible. The NMS patients and control patients had exposure responses that were the same and significantly different from the MH-susceptible patients. They concluded, "These results do not point toward an association between NMS and MH." This supported the previous findings of Krivosic-Horber et al. who determined six NMS patients to be negative for MH susceptibility (5 patients) or equivocal for MH susceptibility (one patient). These authors collectively confirmed their findings in a larger 1994 study that found performed muscle contracture tests on 32 patients with confirmed NMS and found that 29 patients were MH nonsusceptible and 3 patients were MH equivocal. None were classified as MH susceptible. They concluded, "These findings demonstrate the lack of any link between NMS and MH. Therefore, patients with a history of NMS are not likely to be at risk of developing MH and special measures against MH are not required for anesthesia in these patients."

Genetic and epidemiologic data would also seem to be reassuring. A 1996 study did not support an association between NMS and mutations in the RYR1 gene that is associated with a significant percentage of MH cases. Several investigators have reported that NMS patients and their genetically related families have been safely anesthetized with known MH-triggering agents. NMS patients not infrequently present for electroconvulsive therapy (ECT), either in the acute or resolved stages of NMS, and have safely undergone the use of succinylcholine. Since MH is an autosomally dominant-linked disease, it occurs in familial clusters. If NMS and MH were linked in

terms of pathophysiology, one would expect to see increased incidences of MH in families of NMS patients but that has not been observed. Nonetheless, although efforts to demonstrate a direct link between NMS and MH have been unsuccessful, there are still investigators who attempt to conceptualize NMS as a neurogenic form of MH.

In our own practices and teaching, we make careful note of a history of NMS just as we would for any patient who has sustained a potentially life-threatening and poorly understood clinical event. We also take note of those patients who are at risk of NMS based on their medication panels. Generally, if the diagnosis of NMS was reasonably established and documented, we do not postpone a necessary surgery for preoperative evaluation with a caffeine contracture test. We also do not view NMS as an absolute or even relative contraindication to MH-triggering drugs if the risk–benefit ratio otherwise mandates the use of these standard anesthetics and/or succinylcholine. It is of utmost importance that the history of NMS be clearly communicated to the postoperative care teams since the perioperative period is one in which disruption and discontinuation of medication regimens, including and perhaps especially psychotropic and neuroleptic medications, commonly occur. And this is where the true risk to the NMS patient lies.

## TAKE HOME POINTS

- Anesthesia providers and other perioperative clinicians must maintain ongoing vigilance for SS and NMS. Clinical suspicion should be raised if the patient exhibits clonus, rigidity, tremors, agitation, and autonomic instability.
- SS is not biochemically related to MH!
- SS occurs due to an excess of serotonergic activity, typically due to the presence of two or more serotonin agonists or serotonin reuptake blockers. It presents more rapidly and is characterized by hyperactive neuromuscular reactivity such as tremors and clonus.
- There are multiple reports of SS occurring in the perioperative period in patients who are already on standing serotonergic medications. Fentanyl has been implicated in some instances. However, administration of methylene blue poses a greater risk of SS and warrants careful consideration of the risk–benefit analysis as it is a known MAO-inhibitor and a significantly serotonergic agent. It is generally not considered that SS poses a risk for MH and vice versa.
- Perioperative clinicians should be familiar with the Hunter Criteria for Serotonin Toxicity. These criteria include the administration of a serotonergic drug seen in conjunction with clonus, agitation, diaphoresis, tremor, and elevated temperature.
- The pathophysiology of NMS is not related to MH. NMS occurs generally after a sudden reduction or change in D2 dopaminergic action in the CNS. MH is generally caused by a genetic defect variant of one or more types in skeletal muscle receptors.

- NMS and MH share some clinical features and are both treated with dantrolene.
- Reports in the 1980s suggested a link between NMS and MS in terms of causation and cross risk factors. However, a number of subsequent caffeine–halothane-contracture tests performed on confirmed NMS patients have not demonstrated increased MH-susceptibility.
- All patients with a history of or risk for significant clinical peril—including NMS—should be anesthetized with the utmost caution. However, at present there is not compelling evidence that mandates avoidance of MH-triggering drugs, should they otherwise be called for in the anesthetic plan.

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# Drug-Drug Interactions Are Now Necessary Knowledge for the Anesthesia Provider and We Can Help

Neil B. Sandson, MD and Catherine Marcucci, MD

Drug–drug interactions (DDIs) first came to public attention with the Libby Zion case in 1984. Ms. Zion was a college student who died of cardiac arrest shortly after being admitted and treated by two residents whose orders were approved over the phone by their attending physician. Most people in the medical profession as well as the lay public recognize this case as the incident that started the ball rolling on reform of resident work hours. What is sometimes forgotten is that a significant DDI almost certainly contributed to her death—the patient, who was on a standing dose of phenelzine (a monoamine oxidase inhibitor) received a dose of meperidine.

Despite the Libby Zion case, DDIs remained a largely overlooked topic in clinical medicine until the early 1990s. Several things happened at that time. First, a significant number of patients taking both tricyclic antidepressants and fluoxetine (Prozac) or paroxetine (Paxil) began developing Torsades de pointes arrhythmias and this was duly reported in the literature. Second, the earliest, pioneering work on "anesthesia DDIs" that referenced and detailed the basic science of the cytochrome P450 (CYP 450) family of enzymes was published by Evan Kharasch, MD PhD. These papers remain relevant to our clinical practice today.

Unfortunately, DDIs were a topic of interest mostly to psychiatrists and internists for many years thereafter, with other fields of medicine often regarding this as more trouble than it was worth. However, that opinion is changing. Anesthesia providers have more recently come to appreciate the potentially profound impact that DDIs can have on morbidity and mortality, both during procedures and perioperatively. For example, DDIs with significant clinical sequelae can happen with the coadministration of fentanyl/ritonavir, midazolam/carbamazepine, and ropivacaine/fluoxetine. These complications can inconvenience, and sometimes they can result in significant morbidity and even mortality. The safe and conscientious anesthesia practitioner needs to roll up their sleeves and grapple with this clinical issue.

Fortunately, a comprehensive textbook was recently published on this subject, "A Case Approach to Perioperative Drug-Drug Interactions." Although we may be accused of partiality, this book is a treasure trove of information and resources designed to assist the busy anesthesia clinician in navigating the troubled waters of DDIs arising from complex medication regimens in our complicated patients. Whether you want to master the subject on a larger scale, or start to explore specific interactions, this text will be a valuable aid in the process of tackling DDIs. Best of all, the proceeds and royalties from a Case Approach to Perioperative Drug-Drug Interactions are pledged to the Foundation for Anesthesia Education and Research in perpetuity.

## TAKE HOME POINTS

- Drug–drug interactions are not new! The DDI knowledge base is something that every anesthesia clinician should now be working to master.
- We recommend a review of the seminal work of Evan Kharasch, MD PhD on the subject of the cytochrome P450 system and drug–drug interactions, starting from the 1990s to the present. And we also recommend our comprehensive DDI book for further reading!

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# The Six Patterns of Cytochrome P450 Drug-Drug Interactions Relevant to the Perioperative Clinician

Catherine Marcucci, MD and Neil B. Sandson, MD

As we stated in Chapter 92, we strongly feel that the anesthesiology community is uniquely positioned to lead the way for other perioperative clinicians in awareness of potential perioperative drug–drug interactions (DDIs). It is incumbent upon anesthesia providers to undertake a step-by-step approach to learning the DDIs that are relevant in the perioperative period, starting with the basics. Remember that there are many types of DDIs, both pharmacodynamic and pharmacokinetic, and there are subsets of these classifications as well. However, an important subset of pharmacokinetic perioperative DDIs involves those mediated by the cytochrome P450 enzymes found chiefly in the liver microsomes. These enzymes are chiefly responsible for the Phase I metabolism of drugs. This class of DDI is distinguishable from other DDIs that are clinically relevant to the anesthesia provider such as the interaction of perioperative medications that results in serotonin syndrome, or precipitation in an intravenous line, or the DDI between sugammadex and oral contraceptives, which is a binding interaction.

So, to put it another way, perioperative DDIs are a "universe" and DDIs involving the cytochrome (CYP) 450 system is one of the larger and more important "galaxies." When looking at this DDI galaxy, it is most important to learn the CYP450 enzymes and what drugs serve as substrate, inducers, and inhibitors for those CYP 450 enzymes when the drugs are administered concurrently. But when it comes to DDIs, sequence also matters! The chronologic patterns in which substrates, inhibitors, and inducers are combined has significant implications for detection of the potential DDIs, and thus clinical consequences. There are six basic chronologic patterns of DDIs.

## Pattern 1: An Inhibitor Is Added to a Substrate

This pattern generally results in increases in substrate levels. This is one of the easiest DDI patterns to detect. If the substrate has a low therapeutic index, toxicity may result unless care is exercised (such as closely checking blood levels or lowering substrate

dosages in anticipation of the interaction).

**Example:** Trimethoprim-Sulfamethoxazole (TMP/SMX) Is Added to Warfarin

Warfarin is a CYP2C9 substrate and TMP/SMX (Bactrim) is a 2C9 inhibitor. The addition of TMP/SMX impairs the ability of 2C9 to metabolize warfarin, leading to an increase in the International Normalized Ratio (INR). This particular interaction might be encountered by clinicians in the preoperative evaluation center. For example, consider the situation in which you have a 65-year-old lady who is on warfarin for a history of leg deep vein thrombosis who has been experiencing recurrent urinary tract infections. Another example of a potential inhibitor-added-to-substrate DDI might occur when amiodarone (also a CYP2C9 inhibitor) is added to medication regimen of a patient on warfarin, perhaps in an ICU setting.

## Pattern 2: A Substrate Is Added to an Inhibitor

This pattern may cause difficulties if the substrate has a low therapeutic index and is titrated according to preset guidelines that do not take into account the presence of an inhibitor. If the substrate is titrated to specific blood levels or to therapeutic effect, or with an appreciation that an inhibitor is present, then toxicity and/or excessive drug effects are less likely to arise.

**Example**: Midazolam Is Added to Diltiazem

Midazolam is a CYP3A4 substrate and one of our most commonly used drugs, both in the oral and intravenous forms. Diltiazem is a frequently used antihypertensive medication, and it happens to be an inhibitor of 3A4. The use of midazolam in standard dosages when coadministered with diltiazem has been reported to increase midazolam levels and thus prolong sedation and delay the time until extubation can be safely accomplished.

## Pattern 3: An Inducer Is Added to a Substrate

This pattern generally results in decreases in substrate levels. This is also a fairly easy pattern to detect. A decrease in levels of the substrate may result in a loss of efficacy of the substrate, unless blood levels are followed and/or the substrate dosages are increased in anticipation of the interaction.

**Example**: St. John's Wort Is Added to Ethinylestradiol Oral Contraceptives

St. John's wort (SJW) is an herbal supplement that is most commonly taken for its supposed antidepressant effects. Commercially available extracts of St. John's wort

contain varying amounts of several compounds including hyperforin. Hyperforin is an inducer of CYP3A4 and CYP2C9. Many oral contraceptives contain ethinylestradiol and a progesterone component, both of which are primarily metabolized by 3A4. St. John's wort extracts with hyperforin contents of less than 1% are not likely to result in unintended pregnancy. However, a number of commercial SJW products contain up to 5% hyperforin and may pose a risk for patients and caregivers who are not aware of the potential DDI. Another example of an inducer added to a substrate involves the addition of pan-inducer, such as rifampin, to methadone. This scenario might occur in the pain clinic.

## Pattern 4: A Substrate Is Added to an Inducer

This pattern may lead to decreased drug effect of the substrate if the DDI is not taken into account. It may also lead to ineffective dosing of substrates if preset dosing guidelines are followed that do not take into account the presence of an inducer. If the substrate is titrated to specific blood levels or to clinical effect, or with an appreciation that an inducer is present, then dosing is more likely to be effective.

**Example**: Vecuronium Is Added to Phenytoin

The metabolism of vecuronium occurs primarily in the liver by liver microsomes to 3-desacetylvecuronium. Only about 25% of the metabolism of vecuronium occurs in the kidney. The induction of the CYP450 system by phenytoin and many other antiepileptics has been well described. Phenytoin is a pan-inducer of multiple hepatic microsomal enzymes when it is given on a chronic basis. Thus, the effect of vecuronium given to a long-term phenytoin patient is to exhibit increased clearance of nondepolarizing neuromuscular blocking agents, probably through substrate–inducer interaction at multiple enzymes.

## Pattern 5: Reversal of Inhibition

A substrate and an inhibitor have been coadministered and equilibria have been achieved, and then the inhibitor is discontinued. This leads to a resumption of normal enzyme activity and generally results in decreases in levels of substrate and increased metabolite formation. This may result in loss of efficacy of the substrate unless blood levels are followed and/or substratedosages are increased in anticipation of the reversal of inhibition.

**Example**: Fluconazole Is Discontinued in the Presence of Prednisone

This is a possible ICU situation. Fluconazole, a 3A4 inhibitor, and prednisone, a

3A4 substrate, have been stably coadministered at appropriate dosages, yielding appropriate prednisone blood levels and clinical efficacy. The fluconazole is then discontinued, resulting in a cessation of 3A4 inhibition. 3A4 is then more available to more efficiently metabolize the prednisone, leading to a significant decrease in the prednisone blood level, in one known case producing an Addisonian crisis.

## Pattern 6: Reversal of Induction

A substrate and an inducer have been coadministered and equilibria have been achieved, and then the inducer is discontinued. This results in decreased amounts of available enzyme, leading to increased levels of substrate and decreased metabolite formation. This may result in substrate toxicity if the substrate has a low therapeutic index, unless blood levels are followed and/or substrate dosages are decreased in anticipation of the reversal of induction. Reversal of induction is generally a gradual process taking 1 to 3 weeks, but when the inducer is smoked tobacco, this can occur more quickly, often within 1 week.

**Example**: Smoked Tobacco Is Discontinued in the Presence of Clozapine

Smoked tobacco is a CYP1A2 inducer. Clozapine (Clozaril) is an important medication for patients with treatment-resistant schizophrenia. It is principally a 1A2 substrate. Unfortunately, smoking is highly prevalent in the schizophrenic population. Consider the situation of a schizophrenic patient who is a heavy smoker who has been stably maintained on clozapine and whose dosage has been titrated to clinical efficacy with serial blood levels. If this patient is then admitted to a surgical or trauma service with sudden, enforced cessation of smoked tobacco, he will experience a sudden cessation of 1A2 induction. This will result in decreased metabolism of clozapine and a resulting increase in clozapine blood levels, possibly to a degree of toxicity that includes seizures.

## Remember That These Clinical Effects Are Reversed If the Substrate Is a Prodrug!

Prodrugs require metabolism from an inactive parent compound to an active metabolite for clinical efficacy. When pro-drugs (hydrocodone, tramadol, cyclophosphamide, etc.) are the substrates in question, the clinical concerns of the above DDI patterns are reversed. Let us look at this a bit more closely. In the Pattern 1 example above (an inhibitor is added to a substrate), warfarin is the substrate and Bactrim is the inhibitor. When Bactrim is added to the medication panel of a patient on warfarin, the metabolism of warfarin is impaired, leading to excessive and unintended anticoagulation. In other

words, the clinical concern is "toxicity." However, if the substrate is an analgesic such as hydrocodone, it requires metabolism by CYP2D6 to its active form, which is hydromorphone. If the patient on hydrocodone is then placed on a 2D6 inhibitor such as ritonavir or quinidine, the parent drug will not be metabolized to its active form and the clinical result is loss of efficacy, not toxicity. Similarly, the pattern 3 concern that the substrate is a prodrug would be toxicity, not loss of efficacy, and so forth.

## TAKE HOME POINTS

- The sequence in which interacting drugs are added to a regimen affects the likelihood of detecting a DDI.
- The patterns are inhibitor added to substrate, substrate added to inhibitor, inducer added to substrate, substrate added to inducer, reversal of inhibition, and reversal of induction.
- Patterns 1 and 3 are the easiest to detect, patterns 2 and 4 somewhat more difficult, and patterns 5 and 6 are the most difficult to detect.
- For Patterns 5 and 6 (reversals of inhibition and induction, respectively), detection of these DDIs is unlikely to be aided by DDI software or electronic medical record programs. Only an integrated understanding of this paradigm will provide reliable protection from falling victim to these patterns!
- If the substrate in question is a prodrug (requires metabolism to a pharmacologically active form), then the clinical effects of the DDI are reversed.

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# Don’t Spend Time Rereading Tom Clancy Novels Until You Have Mastered These Basic Drug-Drug Interactions

Catherine Marcucci, MD, Randal O. Dull, MD PhD, Laura A. Donegan, MD FACP, and Neil B. Sandson, MD

You are between cases and decide to run down to the cafeteria to get some lunch. While there you run into a friend from medical school who works in your hospital’s busy Internal Medicine practice. She asks if you have any ideas or references on what might cause a patient who underwent a foot and ankle surgery with regional anesthesia and sedation to remain excessively sedated for several hours past the anticipated PACU discharge time. Her patient is a 64-year-old male, generally healthy and no standing medications except for vitamin supplements, who states that he is determined to “get to the bottom of it” and “wants to be tested for something” and has asked for her help. What do you tell her?

We don’t generally advocate for the rote memorization of huge tables of drug–drug interactions (DDIs). Still, it is handy to have a modicum of information pertaining to the most important DDIs down pat as you start to master the larger subject of perioperative DDIs. You also have to be able to answer some basic questions when you are curbsided in the cafeteria! We have pulled together the following set of notes for quick reference and as a jumping off point for your further study—but remember, this is the information that is necessary but not sufficient if you are going to keep your patients and yourself out of perioperative DDI trouble, as well as provide support for your colleagues who have “anesthesia questions.”

As we mentioned in Chapter 93, it is helpful to think of the entire set of potential DDIs that the anesthesia provider might encounter as a universe. There are two sub-universes: pharmacodynamics DDIs and pharmacokinetic DDIs. Within the universe(s) are galaxies and within the galaxies are solar systems.

One very important “galaxy” in the pharmacokinetic universe concerns DDIs that are mediated by cytochrome P450 enzymes, found chiefly, but not exclusively, in hepatocytes. The cytochrome P450 system is involved in Phase I (oxidative)

metabolism. If you are going to commit anything pertaining to perioperative DDIs to memory, we respectfully submit that you start with the highlights of the cytochrome P450 system below. Some individuals display genetic variants of these enzymes that vastly alter drug metabolism. Typically, genotyping occurs in order to elucidate etiology of either intolerance or inefficacy of a given drug regimen.

Here are the main CYP450 enzymes:

**Cytochrome P450 1A2:** Found exclusively in the liver, accounts for about 10% to15% of the metabolism accomplished by the major CYP450 enzymes. Highly polymorphic enzyme with at least 15 alleles identified to date and single point mutations can cause variability in enzyme expression. Clinically significant DDIs may be difficult to predict as enzyme expression can vary up to 40-fold from individual to individual, based on ethnic factors as well as enzyme induction or inhibition by foods, smoked tobacco, and medications.

This is the enzyme that is affected significantly by foods—1A2 is induced by brassica vegetables (kale, cauliflower, broccoli, greens, Brussels sprouts, cabbage), charred meats, and grape juice. The enzyme is inhibited by apiaceous vegetables (carrots, celery, parsley), caffeine, and grapefruit juice.

CYP1A2 is strongly and rapidly induced by smoked tobacco.

**Cytochrome P450 3A4:** This enzyme is a "must-know" for perioperative providers. It is the "workhorse" of the CYP450 system. This enzyme accounts for the majority of Phase I biotransformation of both endogenous biochemicals and xenobiotics. It is estimated to have a majority or minority role in metabolizing from 50% to 70% of currently administered supplements and medications. It also functions as a sort of "backup" enzyme if enzymatic action at other P450 locations is strongly inhibited or lacking due to genetic variability. There are no 3A4 poor metabolizers (a human being would die without it) and there is very little 3A4 genetic polymorphism; however, there is a 10-fold to 30-fold variability of metabolic efficiency based on ethnic, cultural, age, gender, and dietary factors, and presence of liver and intestinal disease.

There are many substrates, inducers, and inhibitors of CYP3A4. Many commonly used analgesic and sedative drugs are CYP3A4 substrates. These include **midazolam, ketamine, fentanyl, alfentanil, sufentanil, methadone, buprenorphine, and most local anesthetics.** Other 3A4 substrates include calcium channel blockers, many statins, steroids, tricyclic antidepressants, antipsychotics, macrolide antibiotics, and carbamazepine.

CYP3A4 inducers include ritonavir, many anticonvulsants, rifampin, and St. John's wort (SJW).

CYP3A4 inhibitors include "azole" antifungals such as ketoconazole and

itraconazole, some selective serotonin reuptake inhibitors (SSRIs), and some quinolone antibiotics. Grapefruit juice is such a potent inhibitor of intestinal CYP3A4 that it is not allowed on some hospitals' dietary menus.

**Cytochrome P450 2B6:** About 2% to 10% of the CYP450 system found in liver, lung, kidney, and intestine. The importance of this enzyme is only just being fully understood. Expression and inducibility are highly variable based on age and ethnicity. It has an emerging profound role in anesthesia since it is considered the chief metabolic enzyme of **propofol.** It also metabolizes **ketamine** when it is given at subanesthetic dosages. CYP2B6 is a main mediator of the metabolism of methadone. This is a CYP enzyme to watch as new studies appear in the literature.

**CYP2C9:** Metabolizes a number of anesthesia medications including propofol (30% to 50% of total metabolism), ketamine (30% to 40%), diazepam (5% to 10%), and halothane (10% to 20%).

CYP2C9 metabolizes pain medications including celecoxib, hydromorphone, and several NSAIDs including ibuprofen, indomethacin, naproxen, and diclofenac. It also metabolizes a number of important perioperative drugs such as barbiturates (which also induce the enzyme), warfarin, carvedilol, glyburide, glipizide, angiotensin receptor II antagonists, and sertraline.

Inducers of 2C9 include our old friends the pan-inducers phenytoin and carbamazepine.

CYP2C9 inhibitors include amiodarone, fluconazole, and sulfamethoxazole.

There can be a 10-fold difference in CYP2C9 between individuals—this is one of the enzymes that can be genotyped to determine dosage parameters, for example, to determine an apparent overresponse to warfarin (underactivity of the 2C9 enzyme leading to less than expected metabolism of the warfarin S-enantiomer, which produces excessive drug effect).

**CYP2C19:** Another CYP enzyme that is characterized by genetic polymorphism resulting in poor and extensive metabolizers. About 5% of Caucasians, 5% of Africans, and 20% of people with Asian ethnicity are thought to have deficient 2C19 activity. Not noted for metabolism of anesthetic agents but metabolizes other important perioperative medications such as clopidogrel, proton pump inhibitors, and several antidepressants and anticonvulsants.

Inhibitors of 2C19 include omeprazole, cimetidine, ritonavir, fluvoxamine, and isoniazid.

Inducers of 2C19 include phenytoin, carbamazepine, and rifampin.

**Cytochrome P450 2D6:** Constitutes about 2% to 5% of the body's CYP450 enzymes

but metabolizes about 25% of current drugs. Great phenotypic variation due to genetic polymorphism—patients can be poor metabolizers (no CYP2D6 function), intermediate metabolizers, extensive metabolizers (normal 2D6 function), or ultrarapid metabolizers (increased 2D6 function). Ethnicity is a factor in 2D6 variability. Caucasians (5% to 10%) and 2% of Chinese patients are poor metabolizers. Reduced metabolism may be as high as 50% in some Asian populations. Populations that may exhibit ultrarapid metabolism are Africans (up to 30% of the population) and Caucasians (up to 1% to 2% of the population). The Roche Amplichip analyzes polymorphisms for 2D6 and 2C19. At present this technology is used mostly for the cohort of psychiatric patients, for example, when adjustment of risperidone dosing is being considered.

There are no known inducers of 2D6.

Common perioperative drugs metabolized by 2D6 are **opioids** (tramadol, hydrocodone, codeine), although it bears mentioning that these are all prodrugs with regard to this enzyme. The parent drugs are only modestly effective analgesics, and require metabolic conversion to significantly more analgesically effective metabolites. Example: CYP2D6 converts codeine to morphine. Variations in 2D6 limit a poor metabolizer's response to codeine, but Africans may be fast metabolizers and experience an immediate and strong response. Other perioperative drugs that are substrates are beta-blockers, some antiarrhythmics, tricyclic antidepressants, and several antipsychotics. Inhibitors of 2D6 are several SSRIs, ritonavir, bupropion, quinidine, and goldenseal.

**Cytochrome P450 2E1:** Found in hepatocytes and important for detoxification. It performs partial metabolism of ethanol, isoflurane, sevoflurane, desflurane, enflurane, and halothane. Considerable genetic variability, which has emerging importance with regard to ethanol-mediated liver damage and ethanol-mediated changes in the metabolism of other drugs.

Inducers are ethanol, tobacco smoke, and isoniazid. That's right—ethanol induces ethanol detoxification.

## Summary of Cytochrome P450 Metabolism of Intraoperative Drugs

**Inhalational anesthetics:** Metabolized by 2E1 in the liver. We Homo sapiens metabolize 10% to 20% of halothane, 0.2% of isoflurane, and do not metabolize nitrous oxide. Approximately 3% of sevoflurane is metabolized to two renal toxins—hexafluoroisopropanol and inorganic fluoride, but their quantities are not significant. Only 0.02% of an administered dose of desflurane is metabolized, predominantly to trifluoroacetic acid.

**Propofol:** Metabolized by CYP2B6 in the liver and also at extrahepatic sites and about 30% to 50% of metabolism is by CYP2C9.

**Ketamine:** Metabolized by CYP3A4 at anesthetic doses with some metabolism also by CYP2B6 at subanesthetic doses.

**Midazolam:** Metabolized by CYP3A4, lack of sedative efficacy can be seen when coadministered with 3A4 inducers such as carbamazepine and phenytoin. Increased sedation may be seen when coadministered with 3A4 inhibitors such as diltiazem, itraconazole, and goldenseal.

**Fentanyl:** Metabolized by 3A4

**Codeine:** A prodrug, it requires metabolism by 2D6 to morphine for analgesic efficacy

**Methadone:** Metabolized mostly by CYP3A4 but also by 2B6 and 2D6

**Local Anesthetics:** Ropivacaine, lidocaine, and mepivacaine are metabolized by 1A2 and 3A4. Bupivacaine is metabolized by 3A4, 2D6, and 2C19.

**Vecuronium:** Multifactorial metabolism by CYP liver enzymes and also metabolized in the kidney. Metabolism is enhanced when coadministered with the cytochrome P450 pan-inducers phenytoin and carbamazepine.

**Rocuronium:** Multifactorial metabolism by CYP liver enzymes and also exhibits enhanced metabolism when coadministered with pan-inducers phenytoin and carbamazepine.

**Note:** The metabolism of **morphine** and **hydromorphone** is chiefly by UGT2B7. The UGT enzymes are "first-cousins" to the cytochrome P450 system and are involved in Phase 2 conjugative metabolism. Morphine is also eliminated by the P-glycoprotein transport system.

So, what do you tell your friend from medical school? Here is your email back to her:

## Case Examples

Hi Carol—for sedation in cases like this the patients typically get propofol, midazolam, fentanyl, and even sometimes a touch of ketamine. The sedating drugs are generally substrates of cytochrome P450 (CYP) 1A2 and 3A4. Both of these enzymes can have 20-fold to 30-fold variability in gene expression, depending on genetics, age, culture, and so forth. Do you still have a copy of A Case Approach to Perioperative Drug-drug

Interactions (DDI Book) that I sent you?* If so, look on pages 37 and 41. If you would really want to test to see if the patient is something of a "low expressor," you could send out for an assay for these enzymes. Although it might be somewhat expensive and I don't think insurance will pay. This tiptoes toward individual patient genomic medicine… There are a number of easily accessible vendors who perform this testing.

The next thing to do is to check to see if the patient was on a CYP1A2 or CYP3A4 inhibitor. For CYP1A2 the meaningful inhibitors that we think about are ciprofloxacin, grapefruit juice, and fluvoxamine. Also, and this is a big one, potentially, caffeine, which is a CYP1A2 substrate but you can get into some meaningful competitive inhibition with just a couple of cups every day, especially if the patient is a low-normal expresser of the gene. For CYP3A4, inhibitors are ketoconazole, fluoxetine, fluconazole, erythromycin, and clarithromycin, so check if the patient has been on antibiotics. Also, is he currently being treated for depression as some of the SSRIs are 3A4 inhibitors. The DDI book goes into a number of cases, look at Parts VII and IX. I would ask about how much grapefruit juice he drinks and whether the patient takes any herbal or supplements on his own or has been on a crazy carrots and celery diet.

*Shameless self-promotion, but, then again, every single last penny of royalties is donated to the Foundation for Anesthesia Education and Research in perpetuity.

## TAKE HOME POINTS

- One of the most important ways you can start to master perioperative DDIs is to master the basic CYP450 enzymes that are relevant to the drugs we use most.
- CYP1A2 metabolizes lidocaine, ropivacaine, and mepivacaine. This is one of the enzymes that is significantly affected by diet—both in terms of induction and inhibition. Smoked tobacco is a strong 1A2 inducer.
- CYP3A4 is the workhorse of the cytochrome P450 system. It metabolizes midazolam, ketamine, fentanyl, alfentanil, sufentanil, methadone, and most local anesthetics including ropivacaine, lidocaine, mepivacaine, and bupivacaine.
- CYP2B6 metabolizes propofol, most probably in the liver but also at extrahepatic sites.
- CYP2C9 is also partially responsible for metabolism of many perioperative anesthesia drugs including propofol, ketamine, diazepam, and halothane. It is one of the enzymes for which genotyping is done to establish dosage parameters. Amiodarone can inhibit 2C9 and extend the half-life of ketamine.
- CYP2D6 metabolizes some of the opioids (tramadol, codeine, hydrocodone) and

bupivacaine. It has great genetic polymorphism and patients can range from poor metabolizers at 2D6 to ultrarapid metabolizers. There are no known inducers.

- CYP2E1 metabolizes halothaane, 3% of your sevoflurane, and a tiny amount of desflurane.

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# Drug-Drug Interactions and the P-glycoprotein Pump—Be Vigilant With Patients on Digoxin

Catherine Marcucci, MD, Erica D. Wittwer, MD PhD, and Neil B. Sandson, MD

In today's medical climate, the anesthesiologist must be prepared to function as a specialist in perioperative medicine. This includes (among many other tasks) a thorough knowledge of the drugs commonly given not just in the operating room (OR), but in the perioperative period, including routes of administration, dosing, and the specifics of drug elimination. Although discussions of pharmacokinetic drug handling most often focus on issues of metabolism and excretion, the emerging importance of the P-glycoprotein transporter highlights the relevance of absorption and distribution as well.

## Physiology of the Transporter

The P-glycoprotein transporter is an ATP-dependent pump that extrudes various compounds (substrates) from protected intracellular domains. For example, P-glycoprotein lines the lumen of the small intestine. When a P-glycoprotein substrate is absorbed across its concentration gradient into the cytosol of an enterocyte, this transporter acts to then extrude that drug out of the enterocyte and back into the gut lumen. Insofar as this process moves the drug against its concentration gradient, it requires ATP. P-glycoprotein also lines the blood–brain barrier, acting as one of the constituents that minimizes access of xenobiotic substances to the central nervous system. In a manner analogous to the small intestine, P-glycoprotein substrates diffuse from the vasculature into the cytosol of blood–brain barrier capillary endothelial cells, but the pump then acts to extrude them back into the vasculature.

## Substrates and Inhibitors of the P-glycoprotein Transporter

The P-glycoprotein transporter shares many substrates with the cytochrome P450 3A4. **Significant P-glycoprotein substrates include carbamazepine, corticosteroids, cyclosporine, dexamethasone, digoxin, quinidine, diltiazem, morphine, ondansetron, phenytoin, risperidone, tacrolimus, and tricyclic antidepressants.** Dose-finding

studies to determine effective doses of these and other P-glycoprotein substrates have already incorporated these effects.

Many compounds act to inhibit the action of the P-glycoprotein. Thus, P-glycoprotein inhibitors decrease the efflux of P-glycoprotein substrates from enterocytes into the gut lumen. The net effect of this process is that in the presence of a P-glycoprotein inhibitor, there will be greater systemic absorption of substrates at given doses. Similarly, at given intravascular concentrations of P-glycoprotein substrates, there will be more influx past the blood–brain barrier and into the central nervous system. In these instances, **drug toxicity may be a concern.** Significant P-glycoprotein inhibitors include atorvastatin, erythromycin, fluoxetine, lidocaine, lovastatin, midazolam, omeprazole, propranolol, simvastatin, tricyclic antidepressants, and verapamil. For instance, there are reports that coadministration of digoxin with a number of P-glycoprotein inhibitors, including atorvastatin, fluoxetine, and verapamil, among others, will reliably raise serum digoxin levels. Several common fruit juices are known to inhibit P-glycoprotein, including grapefruit juice, apple juice, and orange juice.

## Inducers of the P-glycoprotein Transporter

A smaller number of compounds act as inducers of the production of the P-glycoprotein transporter. When an inducer causes increased presence of the transporter, this leads to enhancement of the pump's action on substrates. Thus, in the presence of P-glycoprotein inducers there will be a decrease in substrate blood levels and less influx from the systemic vasculature into the central nervous system. In these instances, loss of drug efficacy may be a concern. **Significant P-glycoprotein inducers include aspirin, rifampin, St. John's wort, and trazodone.** It has been established that coadministration of rifampin and/or St. John's wort with digoxin will decrease serum digoxin levels through this mechanism.

These lists include a fraction of the known P-glycoprotein substrates, inhibitors, and inducers, and each month a growing number of drugs are found to have a functional relationship with this transporter system. When a patient is taking a P-glycoprotein substrate with a narrow therapeutic index, such as digoxin or tacrolimus, it is prudent to attend to the presence, addition, or deletion of P-glycoprotein inhibitors or inducers from the patient's regimen. A list of known P-glycoprotein substrates, inhibitors, and inducers may be found at www.mhc.com/Cytochromes.

### TAKE HOME POINTS

- Today's anesthesia provider must expand her knowledge base beyond that of the basic anesthetic drugs.

- The P-glycoprotein transporter is an ATP-dependent pump that is relevant in the absorption and distribution of a number of important drugs in the perioperative period.
- Substrates of the P-glycoprotein transporter that are of interest to the anesthesiologist are digoxin, morphine, and ondansetron.
- There are both inducers (St. John's wort and aspirin) and inhibitors (midazolam, fruit juices) of the P-glycoprotein transport pump.
- Be aware of the coadministration of both inhibitors and inducers of the P-glycoprotein pump when the patient is on a drug with a narrow therapeutic window, such as digoxin.

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# Can You Name Six Perioperative Drug-Drug Interactions That Involve Oral Contraceptives? Okay, You Can Now!

Catherine Marcucci, MD and Neil B. Sandson, MD

## Oral Contraceptives

Oral contraceptives (OCs) and non-oral forms of hormonal contraception are ubiquitous drugs in our patient population—up to 28% of women in developed nations take them at any given time. There have been several generations of OCs; however, they all contain ethinylestradiol and/or a progestin component.

OCs "participate" in clinically meaningful pharmacokinetic drug-drug interactions (DDIs) in many ways. For example, they act as substrates and inhibitors in several cytochrome P450-mediated Phase I drug–drug interactions. They also act as upregulators (inducers) of a uridine 5′-diphospho-glucuronosyltransferase (UGT) enzyme in Phase II metabolism and, finally, they are implicated in a clinically relevant binding interaction.

1) **OCs acting as a cytochrome P450 substrate:** This is an important outpatient as well an important inpatient drug–drug interaction to know about. Remember that the CYP450 enzyme system (mostly but not totally in the liver) is responsible for a large share of Phase I (oxidative) metabolism. One of the major enzymes in the P450 family is **CYP3A4**. Both ethinylestradiol and progestin compounds found in OCs are primarily metabolized by CYP3A4, or in other words, OCs are substrates of CYP3A4.

- There is the potential for an "outpatient" DDI when a **3A4 inducer** is added to the patient's prehospital drug regimen. This induction is likely to take place if a patient taking OCs is then prescribed medications such as **phenytoin, carbamazepine, rifampin,** or an herbal supplement such as **St. John's wort (SJW).** The clinical concern is that a patient may present for surgery, pain management, or to the intensive care unit and not realize that she has been incurring a risk of unintended

pregnancy. **Here is a summary of the DDI:**

- **Interaction type:** pharmacokinetic (Phase I metabolic)
- **Substrate:** oral contraceptives
- **Enzyme:** CYP3A4
- **Inducer:** phenytoin, carbamazepine, or St. John's wort
- **Clinical effect:** possible loss of efficacy of contraceptive action and possible unintended pregnancy in the preoperative period.

- **There is the potential for an "inpatient" DDI if aprepitant is given to a patient taking outpatient OCs. Aprepitant**, an antiemetic agent given in the immediate perioperative period, is also a **CYP3A4 substrate,** as well as being a weak 3A4 inhibitor and a somewhat stronger 3A4 inducer. The package insert for aprepitant (Emend) recommends that when receiving even a 3-day course of aprepitant, an alternative method to prevent pregnancy be employed upon initiating aprepitant and for **28 days** after administration of the last perioperative aprepitant dose.
- **Summary:**
  - **Interaction type:** pharmacokinetic (Phase I metabolic)
  - **S**ubstrate: oral contraceptives
  - Enzyme: CYP3A4
  - Inducer: aprepitant
  - Cl**inical effect:** possible loss of efficacy of contraceptive action and possible unintended pregnancy in the postoperative period.

2) **OCs acting as a cytochrome P450 inhibitor:** Remember that OCs also act as inhibitors of both **CYP1A2 and CYP2C19.**

- **Clozapine** is an important outpatient atypical antipsychotic medication, especially for treatment-resistant psychotic patients. Unfortunately, it carries five black box warnings, so toxicity is a big concern. It is metabolized by CYP1A2 and 2C19. OCs are CYP1A2 and 2C19 inhibitors.
- **Summary:**
  - **Interaction type:** pharmacokinetic (Phase I metabolic)
  - **Substrate:** clozapine
  - **Enzymes:** CYP1A2 and 2C19
  - **Inhibitor:** oral contraceptives
  - **Clinical effect:** decreased clozapine metabolism leading to clozapine toxicity (possible seizures and other central nervous system toxicities, cardiac toxicity, and agranulocytosis)
- The local anesthetics **ropivacaine, lidocaine, mepivacaine** are metabolized by 1A2 (as well as CYP3A4). OCs are CYP1A2 inhibitors. Thus, this is a possible "inpatient" interaction to consider if, for instance, a young woman on OCs seems to have an inexplicably long block.

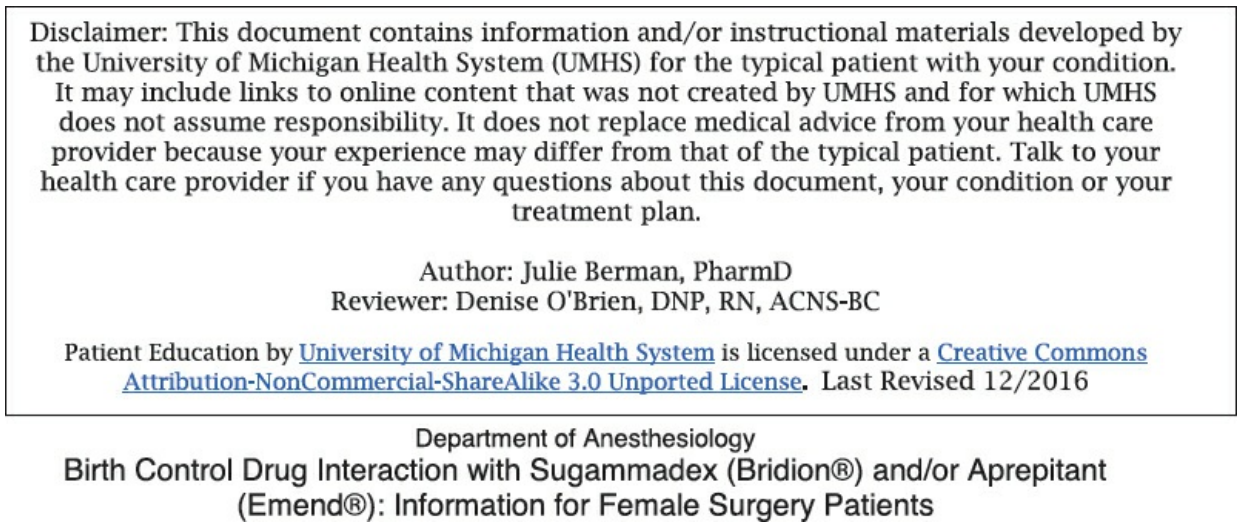
- **Interaction type:** possible pharmacokinetic (Phase I metabolic)
- **Substrate:** local anesthetics, except bupivacaine
- **Enzyme:** CYP1A2
- **Inhibitor:** oral contraceptives
- **Clinical effect:** possible decreased local anesthetic metabolism and prolonged block?

3) **OCs acting as a UGT "upregulator" (inducer): Lamotrigine** is an antiepileptic medication that is also used to treat bipolar disorder. Its metabolism is a bit complicated as it is generally metabolized by **UGT1A4** (remember that the UGT system is the workhorse enzyme system for Phase II or conjugative metabolism). Ethinylestradiol appears to induce increased production of UGT1A4, resulting in the increased clearance of lamotrigine and increased seizure risk.

- **Summary:**
  - **Interaction type:** pharmacokinetic (Phase II metabolic)
  - **Substrate:** Lamotrigine
  - **Enzyme:** UGT1A4
  - **Inducer:** oral contraceptives
  - **Clinical effect:** possible seizures due to lack of lamotrigine drug effect

4) **OCs acting in binding reactions:** These occur with the administration of **sugammadex**. The package insert for sugammadex (Bridion) states that in vitro binding studies indicate that sugammadex may bind to progestogen and that a bolus dose of Bridion is equivalent to one or more missed OC doses. It mandates that the patient use an additional, non-hormonal contraceptive or backup method of contraception for **7 days** following a sugammadex dose. Supplemental contraception is also required if the patient is on a non-oral hormonal contraceptive formulation.

- **Summary:**
  - Proposed interaction type: pharmacokinetic (distribution)
  - Interacting agents: oral contraceptives and sugammadex
  - Clinical effect: loss of contraceptive efficacy and unintended pregnancy in the postoperative period



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Author: Julie Berman, PharmD
Reviewer: Denise O'Brien, DNP, RN, ACNS-BC



Department of Anesthesiology
Birth Control Drug Interaction with Sugammadex (Bridion®) and/or Aprepitant (Emend®): Information for Female Surgery Patients

**Figure 96.1.** © The Regents of the University of Michigan. Used with Permission. For questions contact Michigan Medicine, Patient Education and Health Literacy Program (PEHL). http://careguides.med.umich.edu

Medical institutions have adopted various ways to educate and protect the patient on outpatient OCs or non-oral hormonal contraception who received aprepitant or sugammadex in the perioperative period. For example, at the University of Pittsburgh Medical Center, the electronic health records have been set up to note, in the patient's discharge instructions, the administration of drugs that would potentially render a patient's OCs ineffective. An example of a patient information sheet in the University of Michigan Health System that is available online (http://www.med.umich.edu/1libr/Anesthesiology/BCPInteractionsSugammadexAndApr is shown in Figure 96.1.

**So, let us put this perioperative OC DDI situation into its most succinct and vernacular form:**

- There are six OC DDI situations that we recommend the perioperative provider should be aware of. Three of the six result in loss of OC efficacy and the possibility of unintended pregnancy, either in the preoperative or postoperative period (think CYP3A4 inducers, aprepitant, and sugammadex). Two may raise the risk of destabilization in the perioperative period through seizures, psychiatric destabilization, or cardiac toxicity (think clozapine and lamotrigine). The sixth may possibly contribute to increased local anesthetic toxicity.
- Three of these situations are ones the patient "walks in the door with," while the other three situations are "anesthesia-associated."
- All three of the "walk in the door with" interactions are metabolic—in the first, the patient has taken a medication or supplement in the weeks before surgery that has induced metabolism of her OCs by P450 3A4 enzyme. She is at increased risk of unintended pregnancy.

- In the second prehospital metabolic DDI, the patient's use of an OC has upregulated metabolism of lamotrigine by UGT1A4 and she may have subtherapeutic levels of lamotrigine which could pose an increased neuropsychiatric risk in the perioperative period.
- In the third prehospital metabolic DDI, the patient's use of an OC while on clozapine may have unknowingly raised her clozapine levels and put her at risk for clozapine toxicity.
- The first of the "anesthesia-caused" DDIs is also metabolic—if the patient receives aprepitant (Emend) the anesthesia provider has administered a CYP3A4 inducer in the intraoperative period or PACU. Supplemental contraception is required for 28 days.
- The second of the anesthesia-associated DDIs is a potential decrease in metabolism of local anesthetics, since ropivacaine, lidocaine, and mepivacaine are partially metabolized by CYP1A2 and OCs are 1A2 inhibitors.
- The third anesthesia-associated OC DDI is not a metabolism issue, but rather a binding interaction, and arises if the patient receives sugammadex (Bridion). Supplemental contraception is required for 7 days.
- Coadministration of OCs and an outpatient 3A4 inducer (phenytoin, carbamazepine, rifampin, SJW, etc.): Routine pregnancy screening is performed in all child-bearing age women in many centers. However, be especially vigilant in these patients.
- Coadministration of OCs and clozapine in the outpatient setting: Be vigilant for signs of clozapine toxicity, consider a psychiatric consult and/or serum clozapine level if clinical suspicion is elevated.
- Coadministration of ethinylestradiol OCs and lamotrigine in the outpatient setting: Consider a preoperative psychiatric or neurology consult and/or lamotrigine level, especially if the patient has an independent surgery-associated seizure risk.
- Outpatient OCs and administration of aprepitant by the anesthesia provider—instruct the patient to use supplemental contraception for 28 days.
- Outpatient OCs and administration of sugammadex by the anesthesia provider—instruct the patient to use supplemental contraception for 7 days.

## TAKE HOME POINTS

- You will provide care for patients taking OCs and non-oral hormonal contraception on a constant basis. There are several different approaches to ensure that you are not providing anesthesia for a patient who is unknowingly pregnant. These range all from asking a patient, "Is there any chance you are pregnant?" to obtaining day-of-surgery pregnancy tests. However, the patient's own cognizance of her pregnancy and medical status may have decreased reliability if there is the presence of a metabolic DDI.

- The metabolism of the ethinylestradiol component of OCs maybe induced by drugs and supplements that induce CYP3A4 including phenytoin, carbamazepine, rifampin, and SJW, increasing the risk of unintended pregnancy.
- The ethinylestradiol component may itself act to induce the metabolism of lamotrigine, an important outpatient neuropsychiatric drug.
- OCs may impair the metabolism of clozapine (via CYP2C19 and CYP1A2 inhibition) and the metabolism of some local anesthetics.
- The antiemetic drug aprepitant is also a CYP3A4 inducer. Use in the perioperative period requires the patient to use a backup contraceptive plan for 28 days.
- Sugammadex will decrease the efficacy of outpatient OCs via a binding DDI. Use in the perioperative period requires the patient to use a backup contraceptive plan for 7 days.
- Wouldn't it be great if you could answer questions about these interactions with a level of detail that is above and beyond what is on the patient discharge or information sheet?

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# Wish We Knew Then What We Know Now—A Case of Serotonin Syndrome in the Operating Room

Katarina Bojanić, MD PhD, Juraj Sprung, MD PhD, and Toby N. Weingarten, MD

Your patient is a 60-year-old man who is undergoing sentinel lymph node biopsy with general anesthesia for a squamous cell carcinoma of the scalp. His outpatient medications include amlodipine, hydrochlorothiazide, and fluoxetine 20 mg daily. After a routine propofol/fentanyl induction, the patient is maintained on desflurane. Ten minutes after induction, a total of 0.7 mL of 1% methylene blue is injected into four quadrants of the central parietal scalp. Thirty minutes after induction, the patient exhibits an episode of generalized seizure-like activity lasting 20 seconds. Several minutes later he has another episode. The apparent seizures are not responsive to repeated doses of midazolam. A total of 10 episodes are recorded, each lasting 10 to 20 seconds. When the drapes are taken down, the patient's apparent seizures are noted to be myoclonic activity, originating in the lower extremities, and the patient is also noted to have bilateral lower-extremity rigidity. What is going on with this patient?

**Answer:** This patient on chronic outpatient fluoxetine therapy developed myoclonus consistent with serotonin syndrome after intraoperative of administration of fentanyl and methylene blue.

Major classes of antidepressants increase the activity of serotonin (5-hydroxytryptamine [5-HT]). Serotonin released in the nerve synapses is cleared through two major mechanisms, reuptake into presynaptic neurons and metabolism with outer mitochondrial enzyme monoamine oxidase (MAO) (Fig. 97.1). Therapy with antidepressants that have serotonin reuptake inhibition activity or monoamine oxidase inhibiting (MAOI) activity increase the concentration of serotonin in the synaptic cleft, which increases neurotransmission. Excessive serotonin concentration may result in serotonin syndrome.

## Metabolism of Selective Serotonin Reuptake Inhibitor

Selective serotonin reuptake inhibitors (SSRIs) have been implicated in serotonin syndrome. SSRI, fluoxetine metabolism involves several hepatic cytochrome CYPP450 isoenzymes (Fig. 97.1, lower panel). Specifically, CYP2D6, CYP2C9, CYP2C19, and CYP3A4 participate in methylation of fluoxetine into active metabolites, R- and S-norfluoxetine. Following chronic dosing, both fluoxetine and S- and R-norfluoxetine have the ability to reduce their own metabolic clearance, and fluoxetine and norfluoxetine are also potent inhibitors CYP2D6, while norfluoxetine in addition inhibits CYP3A4. Among SSRIs, paroxetine is the most potent inhibitor, followed in descending order by fluoxetine, sertraline, citalopram, and fluvoxamine Therefore, since prolonged SSRI therapy leads to inhibition of hepatic CYP2D6 isoenzyme; this can pharmacologically covert a normal metabolizer to resemble a poor metabolizer and the net effect may be higher than expected plasma SSRI concentrations.

## Beware of Methylene Blue Pharmacologic Action

Methylene blue is a phenothiazine derivative used intraoperatively for localization of parathyroid glands, mapping of sentinel lymph nodes, treatment of methemoglobinemia and vasodilatory shock. Methylene blue inhibits MAO-A in a competitive fashion, and has been associated with serotonin syndrome in patients receiving SSRIs, serotonin–norepinephrine–selective inhibitors (SNRIs), and tricyclic antidepressants.

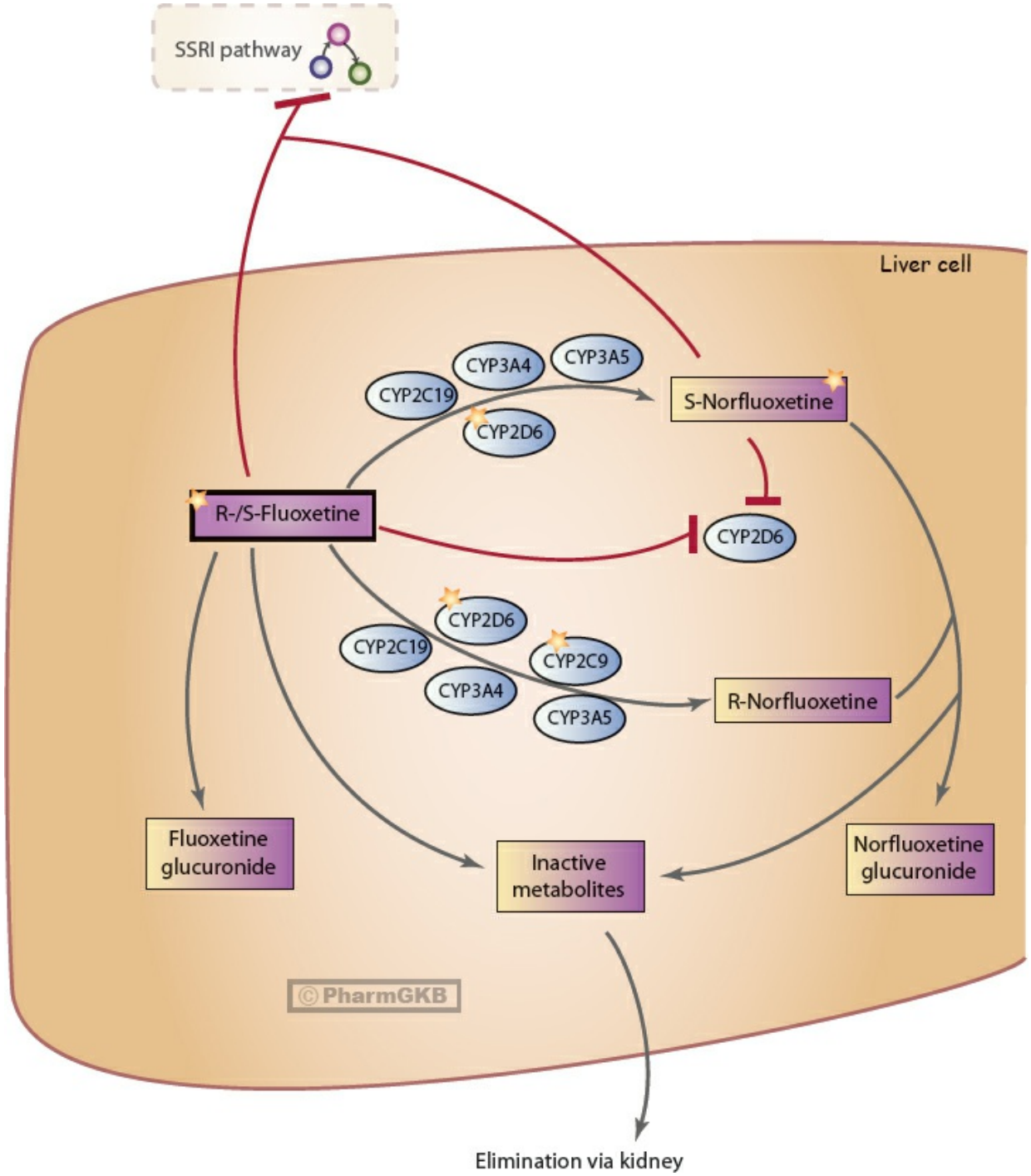


**Figure 97.1.** Metabolic pathway of selective serotonin reuptake inhibitor (SSRI) fluoxetine (**lower panel**) and schematic for development of serotonin syndrome by excessive serotonin in synaptic cleft (**upper panel**). Several isoenzymes are involved in the metabolism of fluoxetine into R- or S-norfluoxetine. S-norfluoxetine has 20 times higher potential for blockade of serotonin (5-HT) reuptake compared to R-norfluoxetine. Red line indicates inhibition of specific isoenzyme by either fluoxetine, R- or S-norfluoxetine, or other medications used in our patient (fish oil, esomeprazole). Serotonin overload in the synaptic cleft with use of fluoxetine and methylene blue. Fentanyl has independent serotonergic properties, which may include both facilitating the release of serotonin from presynaptic neuron (black arrow) as well as weak serotonin reuptake inhibition from synaptic cleft (red line). 5-HT, 5-hydroxytriptamine (serotonin); 5-HIAA denotes 5-HT metabolites: 5-hydroxyindoleacetaldehyde (metabolized by enzyme MAO-A) or 5-hydroxyindoleacetic acid (metabolized by enzyme aldehyde dehydrogenase). (Enzymatic methylation of fluoxetine was modified with permission from PharmGKB

and Stanford University. Available from www.pharmgkb.org/pathway/PA161749012; https://creativecommons.org/licenses/by-sa/4.0/.)

## Drug-to-Drug Interaction: Methylene Blue and SSRI

Careful consideration for potential toxicity should be given when methylene blue are used in patients on serotoninergic antidepressants. Presently there are reports of serotonin toxicity in patients on SSRIs receiving methylene blue. The most prevalent presentation of serotonin syndrome are confusion, agitation, speech abnormalities, increased muscle tone with rigidity, hyperreflexia, and lower-extremity clonus.

When the use of methylene blue is contemplated, SSRIs should be stopped and the stoppage time depends on pharmacokinetic characteristics of SSRI. For example, the half-life of fluoxetine, and its active metabolite norfluoxetine, is 2 to 6 days and 7 to 15 days, respectively, much longer than for fluvoxamine (15 to 26 hours); paroxetine (21 hours); sertraline (26 hours); and citalopram (33 hours). The extended half-life of fluoxetine requires a period of up to 5 weeks for full elimination of drug. Therefore, using drugs with MAO-I potential during this period, despite the fact that fluoxetine has been stopped, can lead to serotoninergic syndrome.

### TAKE HOME POINTS

- Serotoninergic antidepressants are frequently prescribed
- Methylene blue is MAOI
- Combination of serotoninergic antidepressant and intraoperative use of methylene blue may result in serotonin syndrome
- SSRI should be discontinued before the surgery when methylene blue is contemplated, and this period depends on half-life of respective antidepressants
- The U.S. FDA recommends that most serotonergic psychiatric drugs should be stopped at least 2 weeks in advance of methylene blue treatment, while for fluoxetine, with a longer half-life, treatment should be stopped 5 weeks in advance.
- Serotonin syndrome may be a life-threatening complication; therefore it is of utmost importance to have knowledge on which combination of drugs may trigger it.

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## SECTION VI

# EQUIPMENT

98

# Introduction

Brian Mitchell, MD

"Did you try turning it off and on again?"

- The immediate reply to all IT support calls in the British television show "The IT Crowd."

While this one-size-fits-all approach to equipment problems has a certain appeal in its simplicity, it should not be the first solution to problems that arise in the OR. Rather, our patients always receive the best care when we prevent a problem rather than react after an urgent situation occurs and this is never more true than when dealing with equipment issues and failures. Lest you don't already know: In the perioperative environment, turning off a piece of equipment in a willy-nilly-let's-see-if-this-fixes-the-problem-approach can present additional dangers and should be avoided if at all possible!

Most of us don't consider the blood pressure cuff, the pulse-ox, or a syringe pump to be sexy parts of our job. Rather, we often take our equipment for granted as we focus on direct patient care. However, the clinical decisions and actions we make in the operating room often depend on the accuracy of information from our equipment. That reliance only makes sense; our equipment translates a patient's complex underlying physiologic state into numbers, sounds, images, and graphs that we use to make decisions. It is true that our equipment is well-developed, resilient, and will rarely fail, but that does not mean it never breaks nor that its output is always accurate and reliable.

Beyond steps to prevent a problem, we also need to learn and understand the basic troubleshooting steps for when problems do occur. Use these chapters to find the information you need to effectively and efficiently prevent or fix an error with your equipment. The chapters should complement the help you receive from your colleagues when you are not sure how to manage a problem. Take advantage of those around you who can help!

We should also recognize that not all problems are due to equipment failures; we can be the source of errors, too. When we encounter a problem we should evaluate our ability to understand the equipment and its output. It may be helpful to perform a hard

reboot of our own minds. Step back and consider all of the possibilities of why a problem has occurred. Get help from your colleagues, anesthesia technicians, and biomedical engineering.

Then, all that's left is to focus on will be that wonderful piece of machinery called the human body.

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# Pulse Oximetry: Perhaps You Need a Refresher?

Jorge Alberto Pineda Jr, MD and Stephen T. Robinson, MD

Pulse oximetry has become an invaluable tool in the current practice of perioperative medicine. It offers dynamic assessment of oxygenation status, as well as rapid recognition and evaluation of interventions during times of hypoxia on a nearly moment-to-moment basis. Advantages of this monitor include its noninvasiveness, wide availability, portability, and simplicity. However, studies have shown a lack of knowledge concerning the limitations and interpretation of pulse oximetry saturation among both physicians and medical staff.

Pulse oximetry is based on three principles. First, every substance has a unique absorbance spectrum. Hemoglobin has different absorption spectra when oxygen is bound (oxyhemoglobin) compared to when it is not (deoxyhemoglobin). The two light-emitting diodes (LEDs) of the pulse oximeter each emit a different, specific wavelength of light within the red to near-infrared range, and a photo detector measures the amount of light transmitted through the tissue. The second principle is based on the Beer–Lambert law which states that the absorption of light as it passes through a clear nonabsorbing solvent is proportional to the concentration of the solute and the length of the path along which the light travels in that solvent. Finally, the third principle states that the presence of a pulsatile signal generated by arterial blood is relatively independent of the nonpulsatile venous blood in the tissues. By measuring transmitted light several hundred times per second, the pulse oximeter can distinguish the variable, pulsatile component of arterial blood from the unchanging component of the signal made up of the tissue, venous blood, and nonpulsatile arterial blood. The pulsatile or alternating component, which generally comprises 1% to 5% of the total signal, can then be isolated by canceling out the static component.

## Accuracy

Pulse oximetry, or the determination of $SpO_2$ level, is derived from calibration curves of oxygen saturation that were experimentally measured in healthy volunteers. Values

obtained with coincident determination of oxygen saturation by the pulse oximeter were compared with values obtained in in vitro laboratory co-oximetry during normal oxygenation and induced hypoxia. Researchers were limited in the degree of hypoxemia inducible in these volunteers to an arterial saturation ($SaO_2$) of approximately 75% to 80%. Thus, the shape of the curve below these levels must be extrapolated. For peripheral arterial saturation, most manufacturers report accuracy to within ±2% for $SpO_2$ of 70% to 100% and ±3% for $SpO_2$ of 50% to 70%. There is no reported accuracy below 50% saturation. These claims are largely supported by several review studies addressing accuracy by correlating $SaO_2$ with $SpO_2$. Reduced accuracy in this low range does not have any meaningful clinical implications as a $SaO_2$ level of 75% represents a $PaO_2$ level of 40 mmHg.

There is a delay between changes in alveolar oxygen delivery and changes in the $SpO_2$ level. In general, finger probes are slower (24 to 35 seconds) when compared with earlobe probes (10 to 20 seconds). Changing ventilator management to improve oxygenation requires allowing time for the alveolar oxygen concentration to rise, for the blood with higher oxygen content to reach the site of the pulse oximeter probe, for signal processing to occur, and then for display of the processed signal on the monitor as an $SpO_2$ value. Clinicians should allow sufficient time for their interventions to change the pulse oximetry readings.

## Limitations: Signal Artifacts and Optical Interference

The major limitations of pulse oximetry can be divided into two major categories: those arising from optical signal artifact and those resulting from optical interference. Most problems with pulse oximetry arise from signal artifact. Signal artifact can result from false sources of signal or from a low signal-to-noise ratio. Unfortunately, the presence of a sharp pulsatile waveform on the oximeter does not guarantee an accurate signal and the absence of an artifact.

Sources of false signal include detection of nontransmitted light (ambient light or optical shunt) and nonarterial sources of alternating or pulsatile signal. Because light can be a potentially major source of interference, designers divided the LED and photo detector activities into three sensing periods, which can cycle hundreds of times per second. Of these three periods, two use light emitted by the LEDs at each of the two incident wavelengths. During the third period, neither LED is activated and the photo detector measures only ambient light. This measurement is then eliminated from the LED-illuminated sensing periods. Despite this, ambient light still may cause interference. Implicated sources of ambient light interference include fluorescent lights, surgical lamps, fiberoptic instruments, and sunlight. A simple solution is covering the

probe with an opaque shield. An optical shunt occurs when light emitted from an LED reaches the photo detector without passing through an arterial bed. This can happen when the probe is poorly positioned, disconnected from the patient, or when an inappropriate probe is used (e.g., a finger probe placed on the ear). Nonarterial alternating signals can result from repetitive movements of the probe, most often from patient movement. Shivering, movement during cardiopulmonary resuscitation, repetitive cough, and the cycling of ventilators are common potential sources of motion artifact.

Most currently used pulse oximeters use complex algorithms to distinguish signal artifact (noise) from actual signal and will only accept a certain signal-to-noise ratio. However, sometimes noise is processed and presented as a signal. This explains the phenomenon of the oximetry cable hanging empty on the IV pole but the monitor displaying a pulse and saturation. A low signal-to-noise ratio results from absent or low amplitude pulses. Causes include hypotension, hypovolemia, hypothermia, peripheral vascular disease, and iatrogenic causes such as noninvasive blood pressure cuff inflation and vasoconstrictor administration. A low-pulse state would cause a drop out of signal in older models, whereas newer, more sensitive models can detect low signals but may display a false low saturation.

Optical interference can limit the value of pulse oximetry. Several substances in the blood can interfere optically with pulse oximetry. These substances absorb light within the red and near-infrared wavelengths used in pulse oximetry. Carboxyhemoglobin (COHb) and methemoglobin (MetHb) are the most significant potential false absorbers. By conventional two-wavelength pulse oximetry, COHb will appear much like oxyhemoglobin (oxyHb) in the red range, with virtually no effect in the infrared range. The net effect on $SpO_2$ is an overestimation of true oxygen saturation. What occurs in the instance of elevated MetHb level is that the MetHb contributes greatly to the perceived absorption of both deoxyhemoglobin and oxyHb, driving the ratio of relative absorbances calculated by the pulse oximeter to one. When this ratio is one, the calibrated saturation is approximately 85% leading to an underestimation of true oxygen saturation. Because of the existence of other hemoglobin states such as methemoglobin (MetHb) and carboxyhemoglobin (COHb), many newer devices use additional wavelengths to improve accuracy.

Intravenous dyes can produce falsely low-pulse oximetry readings. Changes begin 30 to 45 seconds after dye injection, and recovery to baseline occurs within 3 minutes. Methylene blue causes a profound false decrease in $SpO_2$. Five milliliters of methylene blue has been reported to decrease oxygen saturation to as low as 1%. Oxygen saturation can decrease less significantly after intravenous administration of indocyanine green and indigo carmine. False desaturations with these dyes are also

noted on the multiwavelength co-oximeter.

Skin pigmentation has been shown to affect pulse oximetry. Signal detection failures are more common in patients with dark skin. Darker skin appears to make light penetration more difficult. Nail polish may also affect accuracy of readings and, when problems occur, they appear to arise more commonly from blue or black polish.

## Clinical Application

In most cases a normal $SpO_2$ is a reassuring result, whereas a low $SpO_2$ is an indication for further investigation. Unfortunately a low $SpO_2$ is a very nonspecific finding. Assuming the value is accurate, all aspects of oxygen delivery, including the basic aspects of resuscitation, must be addressed. The clinician must ensure that the airway is patent. Airway obstruction, esophageal intubation, or even endobronchial intubation can cause significant hypoxia or anoxia. The clinician must ensure that the patient has adequate ventilation, oxygen concentration, circulation, and tissue perfusion. In many cases, this can be done quickly by inspecting the patient, the oxygen delivery device, and other patient monitors.

In certain situations, determining the cause of the low $SpO_2$ value can be difficult. Depending on the clinical circumstances you should consider apnea, atelectasis, pneumothorax, low cardiac output, and anemia. Examine the patient, auscultate and verify unobstructed delivery of oxygen. Determine if chest x-ray or other ancillary studies such as an echocardiogram are indicated. Occasionally, measuring arterial blood gas levels to determine the partial pressure of carbon dioxide ($PaCO_2$) and checking the acid–base status to validate the $PaO_2$ may be appropriate.

Pulse oximetry is a measure of arterial oxygen concentration at the site being measured. A normal value obtained at the finger tip does not always permit conclusions to be drawn regarding adequate oxygen delivery to other tissues. A stable but lower $PaO_2$ value could be a symptom of an underlying problem that a normal $SpO_2$ value is masking. Adequate organ and tissue perfusion requires both an adequate perfusion pressure and blood flow to achieve sufficient oxygen delivery. $SaO_2$ and $PaO_2$ have a curvilinear relationship. For $SpO_2$ values in the mid 90s and lower, $SpO_2$ is a reasonable predictor of $PaO_2$. At the highest $SpO_2$ values (99% or 100%), predicting $PaO_2$ is not possible. An $SpO_2$ of 100% can correspond with a $PaO_2$ value ranging from 150 to 600 mmHg. $SpO_2$ values can be unreliable in predicting $PaO_2$ values when $PaO_2$ is high but dropping or is simply lower than expected. For example, during an episode of apnea, $PaO_2$ levels decline; however, a corresponding change in $SpO_2$ level may be delayed, and not show until your response time is limited. Other monitors, such as capnography or apnea alarms, generally provide an earlier warning.

In cases in which the oximeter cannot find a pulse, potential underlying cardiopulmonary problems should be addressed first. If use of a finger probe is causing the problem, changing the probe location may prove successful. Earlobe probes have been shown to produce better signal than finger probes in some cases. Studies have shown that the earlobe is less vasoactive than the finger pad or nail bed and is less susceptible to vasoconstrictive effects. Forehead and nasal probes can also be used. Other solutions include using topical nitroglycerin, local heat, and massage. Even digital blocks and intra-arterial vasodilators via ipsilateral radial artery lines have proven successful without much systemic effect, although many would regard them as extreme interventions. Placement of the sensor on the same extremity as a blood pressure cuff can also cause erroneously low readings while the cuff is inflating and should be avoided when possible.

## TAKE HOME POINTS

- Pulse oximetry monitors oxygenation, not ventilation.
- Pulse oximetry is a widely available, noninvasive, and reliable monitor that provides an early warning of hypoxemia that may not be detected by subjective observation.
- Pulse oximetry uses the differential absorbance of light by oxyhemoglobin and deoxyhemoglobin to estimate oxygen saturation.
- Understanding both the physiologic and technical limitations of pulse oximetry is necessary to use it appropriately. Major aspects to be considered include accuracy, response time, hypoperfusion, "the low-pulse problem," and motion artifacts.

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100

# The End-Tidal $CO_2$ Monitor Is More Than Just a Device to Tell You That "the Tube in the Airway"

Brian Woodcock, MBChB MRCP FRCA FCCM

Anesthesia providers most commonly use a capnogram to confirm tracheal intubation and to exclude the possibility of esophageal intubation. However, the end-tidal $CO_2$ ($ETCO_2$) level shown by the capnogram and the pattern of the capnogram can also indicate many hemodynamic and respiratory conditions. Anesthesia providers should recognize that many conditions may lead to an increased arterial–end-tidal $CO_2$ gradient.

## Review of Capnography

The most commonly used capnometers are of the infrared (IR) light absorption type. The analysis can occur at the machine or in the ventilator circuit. In the first instance, airway gases can be sampled along a narrow tube to the machine. Alternatively, an adaptor placed in the airway circuit uses IR light absorption to measure the $CO_2$ concentration directly in the gas stream. This second method provides a very fast response time and avoids problems with clogged tubing and water vapor condensation. It has fallen out of favor because of the extra weight near the endotracheal tube, a concern about reusing a device within the circuit, and the fact that the externalization of the sensor makes it more prone to damage during usage.

## Capnometry Versus Capnography

Capnometry is the determination of the end-tidal partial pressure of $CO_2$. Capnography is the graphic display of instantaneous $CO_2$ partial pressure versus time during the respiratory cycle. This relation is displayed as a $CO_2$ waveform or capnogram. The simplest use of measured $ETCO_2$ is to follow changes in $PaCO_2$ level. Although the $ETCO_2$ level may be lower than the actual $PaCO_2$ level, in the absence of severe dead-

space effects, alterations in $PaCO_2$ level will be mirrored by changes in $ETCO_2$ level, and these changes can be continuously monitored. This may be particularly useful when changes in minute ventilation are made and $PaCO_2$ levels are changing. The waveform produced by the monitor as a capnogram gives further information in addition to the numeric value of the $ETCO_2$.

## Normal Capnogram

Dead space (ventilated but unperfused airway) can be divided into apparatus and anatomic (or conductive) dead space, which is in series with the alveoli, and alveolar (or physiologic) dead space, which is in parallel with the alveoli.

Apparatus and anatomic dead space causes the initial expired gas to have a $CO_2$ level of zero (phase I, Fig. 100.1). As expiration continues, alveolar gas is detected and the capnogram rises rapidly (phase II). In phase III, known as the alveolar plateau, the apparatus and anatomic dead-space gases have been expired and the gas sampled is from alveoli. If all these alveoli were perfused, then the $CO_2$ level would be that of "ideal" alveolar gas, that is, very close to the $PaCO_2$ level. However, the $CO_2$ level is lower than the $PaCO_2$ level during the plateau because of admixture of gas from unperfused alveoli with a $CO_2$ level of zero (alveolar dead space). This means that the $ETCO_2$ level will be close to the $PaCO_2$ level in patients with low alveolar dead space; however, if alveolar dead space increases (e.g., as in emphysema), then the $ETCO_2$ will be reduced, compared to $PaCO_2$. The difference between end-tidal and arterial $CO_2$ level depends on alveolar dead space and is not altered by changes in apparatus or anatomic dead space.

## Factors Influencing Alveolar Dead Space

Table 100.1 lists the factors influencing alveolar dead space.

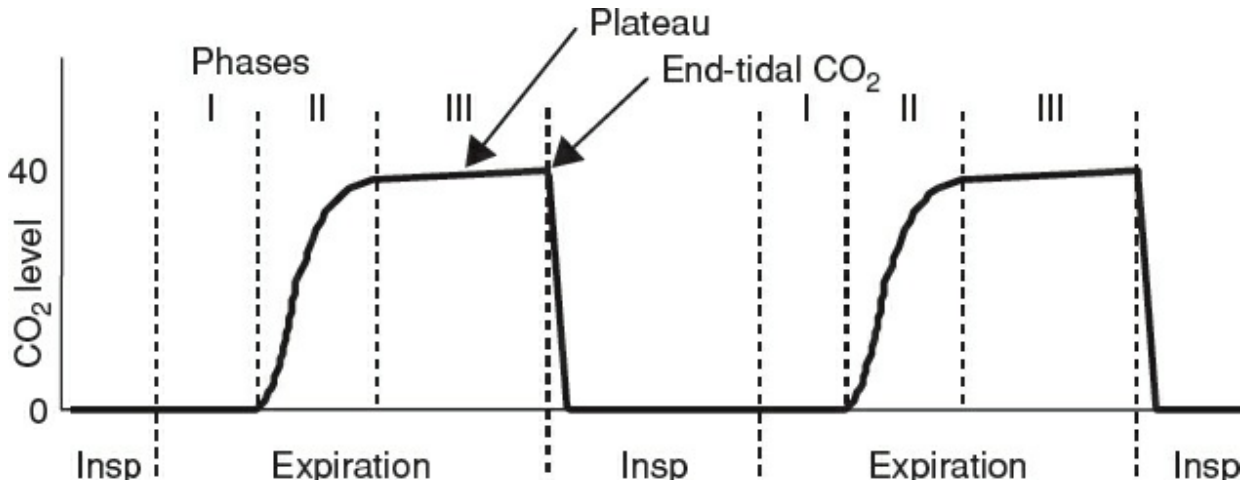

**Figure 100.1.** The normal capnogram. Insp, inspiration.

**Table 100.1 ■ Factors Influencing Alveolar Dead Space**

| Factor | Effect |
|---|---|
| Hydrostatic failure of alveolar perfusion | Gravity increases perfusion to the lowermost portions of the lung. Uppermost portions have a higher V/Q ratio, i.e., dead space |
| Pulmonary embolism | Clot, air, fat, or amniotic fluid reduces perfusion to ventilated alveoli and causes dead space |
| Ventilation of unperfused airspace | Alveolar destruction occurs in emphysema. Bullae |
| Precapillary obstruction to blood flow | Hypoxic pulmonary vasoconstriction results |
| Tidal volume and PEEP | Alveolar dead space increases if tidal volume and PEEP increase excessively |

PEEP, positive end-expiratory pressure; V/Q, ventilation/perfusion.

Ventilation-perfusion mismatch increases the arterial–end-tidal $CO_2$ gradient, and studies have shown this increase to be significantly higher in patients with morbid obesity (body mass index >35 kg/m$^2$) and in patients receiving anesthesia in the lateral position. Increased gradients have also been reported in older patients; in patients with a high American Society of Anesthesiologists' physical status classification system (ASA) score; and during episodes of hemodynamic instability.

## Decreased Capnogram

Gas exchange requires both ventilation and circulation. A markedly depressed or absent capnograph tracing may be due to ventilator circuit disconnection or ventilator malfunction; cardiac arrest or decreased cardiac output; massive pulmonary embolus; or a dislodged, misplaced, or obstructed endotracheal tube. Capnography may thus be the first warning of catastrophic events or complications. The Closed Claims Project review of adverse anesthetic outcomes suggests that there has been a decrease in severity of injury in anesthesia malpractice claims and that anesthesia safety has

improved since the establishment of monitoring standards using pulse oximetry and end-tidal capnography.

$ETCO_2$ monitoring may provide clinically useful information that can be used to guide therapy during cardiopulmonary resuscitation (CPR). The level of the $ETCO_2$ may indicate the adequacy of CPR and can also provide the first evidence of the return of spontaneous circulation.

During the application of a limb tourniquet, the amount of tissue releasing $CO_2$ into the circulation is decreased and $ETCO_2$ level will fall. Decreases in $CO_2$ level may also occur with hypothermia.

## Increases in $ETCO_2$ Level

The earliest warning of a serious hypermetabolic condition, such as malignant hyperthermia, thyroid storm, or severe sepsis, may be a rise in $ETCO_2$ level, reflecting the increase in $PaCO_2$ level. Administration of intravenous bicarbonate leads to generation of $CO_2$ and this is reflected in the tracing within minutes. Other causes of an elevated $ETCO_2$ level include the release of a limb tourniquet; the restoration of blood flow, resulting from unclamping a large artery or vein; and the development of venous $CO_2$ embolism during laparoscopy.

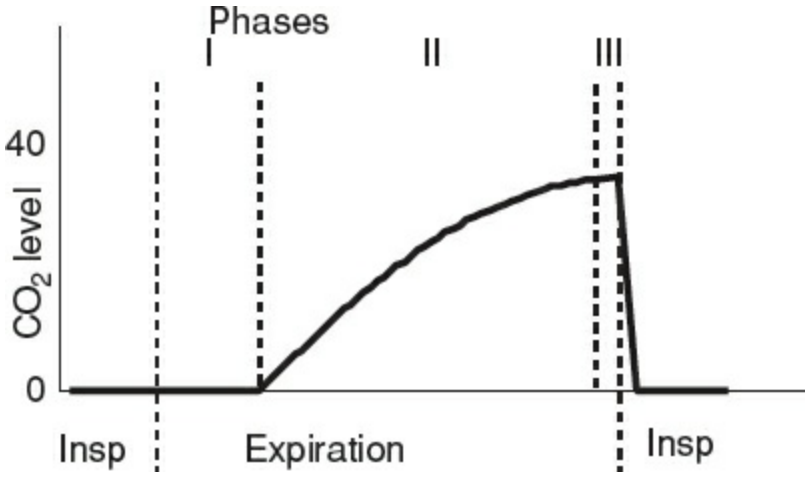


**Figure 100.2.** Capnogram in the presence of bronchospasm. Insp, inspiration.

## Effect of PEEP

The Pa-$ETCO_2$ gradient may be an indicator of optimal levels of PEEP for ventilated patients. As PEEP increases and there is maximal recruitment of gas exchange units, then lung ventilation should be more even, phase II of the capnogram will be shorter, and the Pa-$ETCO_2$ gradient will be reduced. An excess of PEEP can distend alveoli

excessively and redistribute blood flow, causing an increase in alveolar dead space, increasing the Pa-$ETCO_2$ gradient.

## Bronchospasm

Phase II of the capnogram reflects the emptying of bronchopulmonary units; as more units empty into anatomic dead-space gas, the waveform rises. If lung units have differing time constants, due to uneven lung ventilation, then this will be reflected by a slower rise in the phase II of the capnogram (Fig. 100.2.). Phase II may be so prolonged that the alveolar plateau, or phase III, is never reached, resulting in a larger Pa-$ETCO_2$ gradient. This situation may occur with obstructive airway disease, such as asthma or chronic obstructive pulmonary disease. A change in the capnogram pattern to this shape could indicate that the $ETCO_2$ level is no longer a reliable indicator of the $PaCO_2$ level.

## Negative Arterial–End-Tidal Gradient

$ETCO_2$ levels that exceed $PaCO_2$ levels have been reported in the following circumstances:

- Healthy patients during low-frequency, high-tidal volume ventilation
- Pregnant patients
- Infants and children
- Patients that recently have had cardiopulmonary bypass
- Patients that are or recently were exercising

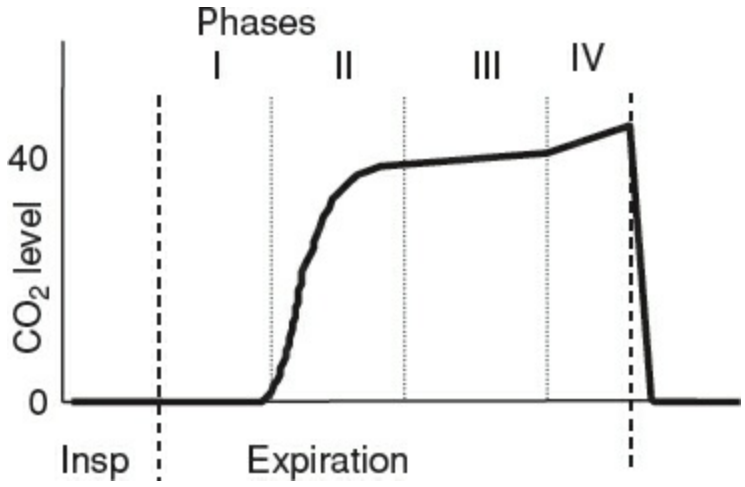


**Figure 100.3.** Phase-IV secondary elevation in plateau $PCO_2$ level. Insp, inspiration.

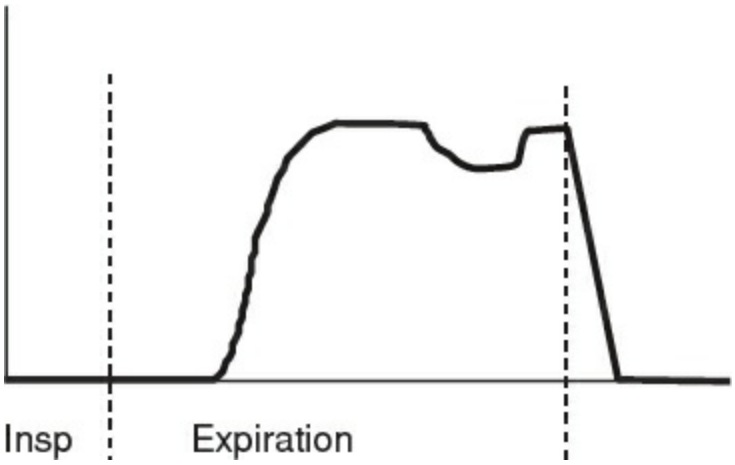


**Figure 100.4.** Curare cleft.

Alveolar $PCO_2$ level varies during the respiratory cycle, being lowest at end-inspiration and highest at end-expiration. Opening of alveoli with long time constants toward the end of expiration allows the addition of gas with a higher $PCO_2$ level, particularly if the alveoli have a low V/Q ratio. This may be seen as a phase IV in the curve of the capnogram, in which there is a secondary rise in the alveolar phase of expiration (Fig. 100.3). This secondary rise may be to a higher level than the $PaCO_2$ level, which is an averaged level due to mixing in the circulation and syringe.

## Alterations in Inspiratory $CO_2$

Elevation of the baseline above zero may indicate rebreathing of expired gas, possibly resulting from exhaustion of the soda lime; malfunction of valves in the anesthesia circuit; or use of a rebreathing system (such as Mapleson A, B, C, or D [Bain], or an E circuit) without adequate fresh gas flow.

## Other Variations in Waveform

Waning neuromuscular blockade may allow small respiratory efforts, causing a dip in the plateau waveform; this is known as a "curare cleft" (Fig. 100.4).

Toward the end of expiration, as expiratory flow decreases to a low level, cardiac contraction may change intrathoracic volume enough to draw gas into the airway from the anesthetic machine circuit. These cardiac oscillations are seen as regular dips at the end of the plateau matching the heart rate (Fig. 100.5). These oscillations may continue into the descending limb of the curve if expiration is prolonged.

## Monitoring Moderate or Deep Sedation

In 2011, ASA amended its Standards for Basic Anesthetic Monitoring to include $ETCO_2$

monitoring to ensure the adequacy of ventilation under moderate or deep sedation. Use of $ETCO_2$ allows detection of airway obstruction, opioid-induced hypoventilation, or apnea well before a drop in oxygen pulse saturation occurs. While continual observation of qualitative clinical signs are also required, only capnometry ensures the adequacy of ventilation with a qualitative and quantitative measurement of the presence of exhaled carbon dioxide and respiratory rate.

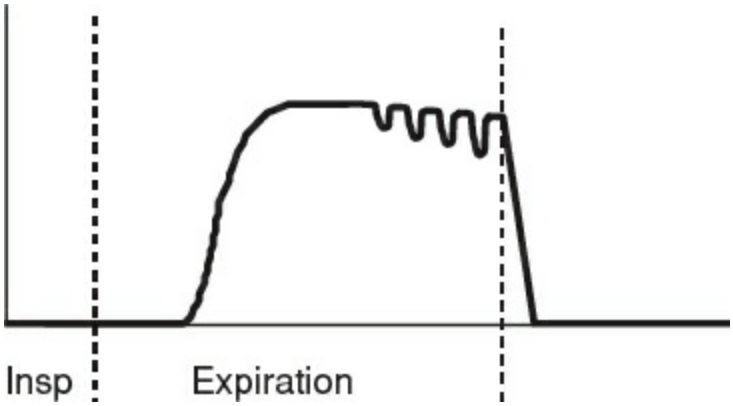


**Figure 100.5.** Cardiac oscillations.

## TAKE HOME POINTS

- Capnography is a standard of care for every general anesthetic and moderate to deep sedation because it monitors the adequacy of ventilation.
- Production of $ETCO_2$ requires both ventilation and circulation.
- Capnography can noninvasively detect many of the catastrophic problems that occur during anesthesia.
- There are many circumstances in which $ETCO_2$ level does not accurately represent $PaCO_2$ level.
- Analysis of the shape of the waveform may give useful information on changes in the patient's condition, the anesthesia circuit, or the effects of surgery.

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# Noninvasive Blood Pressure Management—It's Not Just a Piece of Nylon Around the Arm

Jorge Alberto Pineda Jr, MD and Stephen T. Robinson, MD

The automated, noninvasive blood-pressure cuff is a safe, commonly used monitoring device. It provides consistent, reliable values for systolic, diastolic, and mean arterial pressure (MAP). Blood-pressure–cuff cycling intervals can be set and current monitors can store data to provide trends. Automated devices also provide alarm systems to draw attention to extremes in blood-pressure values. One great advantage of such a monitor is that it frees the anesthesiologist for other tasks. Disadvantages include frequent failure in profoundly hypotensive patients, patients with arrhythmias, and during periods of external compression (surgeon or scrub nurse leaning on it), and movement artifact (shivering or tremors).

## Oscillometry

Most noninvasive devices used in current practice measure blood pressure by oscillometry. In this method, variations in cuff pressure resulting from arterial pulsations during cuff deflation are sensed by the monitor and used to determine pulsations corresponding closely to true mean arterial pressure. The cuff inflates to a pressure above the previous systolic pressure and then deflates incrementally. A transducer senses the pressure changes, which are then processed by a microprocessor. This technique has an accuracy of ±2%. The mean arterial pressure corresponds to the maximum oscillation (maximum amplitude = $A_{max}$) at the lowest cuff pressure.

Systolic and diastolic pressure readings are derived indirectly from formulas that examine the rate of change of the pressure pulsations. It has been determined that systolic and diastolic pressures occur when the amplitudes of oscillation ($A_{systolic}$ and $A_{diastolic}$) are a certain fraction of $A_{max}$. The systolic pressure corresponds to the onset of rapidly increasing oscillations. Algorithms used by different manufacturers vary and are never publicly disclosed, making it difficult for investigators to verify the accuracy of their underlying physiologic principles. In general, the systolic pressure is chosen as the pressure above the mean pressure at which oscillations are increasing in amplitude

and are at 25% to 50% of the maximum ($A_{systolic}/A_{max}$ = 0.25 to 0.5). Diastolic pressure corresponds to the onset of rapidly decreasing oscillations and is more difficult to determine. It is commonly labeled as the point below the mean pressure at which the pulse amplitude has declined to 60% of $A_{max}$ ($A_{diastolic}/A_{max}$ = 0.6), or it is calculated from the systolic and mean arterial pressure, using the following formula: MAP = diastolic + one-third pulse pressure. A major problem with this technique is that the amplitude of the oscillations can depend on several factors other than blood pressure. For example, elderly subjects and patients with "stiff," atherosclerotic arteries have a loss of arterial wall compliance, which is associated with higher systolic and diastolic blood pressure readings using blood-pressure cuffs as compared with values obtained from direct arterial measurements.

## Proper Use

Appropriate sizing and positioning of the blood-pressure cuff are important in measuring pressure accurately. Cuff width should be 20% greater than arm diameter, and the cuff should be applied snugly after any residual air has been squeezed out. The pneumatic bladder inside the cuff should span at least half the circumference of the arm and should be centered over the artery. In general, a cuff that is too large works well and produces little error; however, a cuff that is too narrow yields falsely elevated values for blood pressure because the pressure within the cuff is incompletely transmitted to the underlying artery.

In certain situations, noninvasive blood-pressure cuffs may be used on one extremity but not on another. Cuffs should not be used on an extremity with deep-vein thrombosis, ischemic changes, arteriovenous fistula, or arteriovenous graft. In addition, cuffs should not be applied directly over a peripherally inserted central catheter. If a patient has had a mastectomy or lumpectomy, avoid using cuffs on the involved arm to minimize worsening lymphedema. Caution should be used in patients with pre-existing peripheral neuropathies, as frequently repeated measurements worsen a neuropathy.

In some situations, noninvasive blood-pressure monitoring is inadequate, and placement of an arterial line is indicated. Situations that may require beat-to-beat blood-pressure monitoring include frequent cuff cycling to provide tight blood pressure control over long periods of time, titration of vasoactive infusions, and frequent laboratory draws of arterial blood. Keep in mind that the peripheral arterial line is not without its limitations. For example, in a patient with substantial vasodilation during the period immediately after a cardiopulmonary bypass procedure, blood-pressure measurements obtained using a noninvasive blood-pressure cuff on the arm may be more accurate than a radial-artery invasive line secondary to the cuff's more central location.

## Errors of Measurement

Atherosclerotic lesions in the subclavian or axillary arteries, causing obstruction of flow, may lead to misleadingly low pressure measurement distally in the affected arm. Thus, elderly patients or patients with known peripheral atherosclerosis should have blood pressure verified in both arms, and the arm with the higher blood pressure should be monitored to avoid this "pseudohypotension." If both arms are diseased, resulting in bilateral falsely low pressures, the femoral artery may be the best option for monitoring. Alternatively, if the risks of invasive monitoring are too substantial, relative to its benefit, the noninvasive pressure may be followed as a trend relative to its baseline.

Besides cuff size and bladder placement, other potential sources of error include arrhythmias causing pulse irregularities; small wrinkles or folds in the cuff expanding and changing the cuff's volume suddenly during data collection; and small movements of the patient, which may create excessive artifact. When the heart rate is irregular, the cardiac output and blood pressure vary greatly from beat to beat. Performance of the oscillatory cuff depends on all measurements made during a cycle. Cuff bladders are set to deflate at a manufacturer-specific "bleed rate" which assumes a regular pulse between bleed steps as part of the algorithms used to determine systolic and diastolic pressures. An error caused by irregular beats or by motion of the patient may affect the accuracy of the blood-pressure device.

Anesthetic record data that include significant artifacts should be identified and discarded, or an explanation charted as to why there is a deviation from what is happening clinically. The source of the artifact, such as poor positioning of the cuff, tubing occlusion, patient movement, and intermittent compression by the surgeon, should be removed and the affected data should be discarded. The entire cycle should be repeated if measurements are determined to be unreliable. If it is not possible to remove the source of the artifact, consider moving the cuff to an alternative site.

## Complications

Complications with noninvasive blood-pressure cuffs may occur on rare occasions. These complications include skin irritation and bruising, infection, neuropathy, thrombophlebitis, venous stasis, petechiae, ecchymoses, compartment syndrome, and skin necrosis. Noninvasive blood pressure cuffs should be avoided in patients with certain medical conditions including severe types of osteogenesis imperfecta and epidermolysis bullosa. The pressure exerted by the cuff may result in fracture of the limb where the cuff is placed or trauma to the skin. Compartment syndrome is a serious complication and requires prompt surgical intervention. Patients taking anticoagulants are at an increased risk for formation of hematoma and development of compartment syndrome with use of noninvasive blood-pressure cuffs. These events typically occur

during prolonged periods of use with excessively frequent cuff cycling, which results in local trauma or impaired distal limb perfusion. Other factors that may predispose to the development of compartment syndrome include poor positioning of the cuff across a joint, the continuous pressure of a cuff that has been applied too tightly, or repeated attempts to determine blood pressure in the presence of a malfunctioning cuff or an artifact-producing condition, such as involuntary tremors.

## TAKE HOME POINTS

- Automated noninvasive blood-pressure devices are safe, reliable, and sufficient in most clinical settings.
- The blood-pressure cuff should be properly sized and placed to be effective.
- Problems with accuracy of noninvasive readings may arise in those patients with severe hypotension, arrhythmias, or atherosclerosis.
- Use an arterial line when beat-to-beat monitoring of blood pressure is needed, vasoactive infusions are used to control blood pressure, or frequent laboratory draws of arterial blood gas are anticipated.
- Although relatively safe, this device has been associated with development of complications, including skin irritation, bruising, infection, neuropathy, thrombophlebitis, venous stasis, petechiae, ecchymoses, compartment syndrome, and skin necrosis. We recommend that clinicians take a moment to document the "pre-cuff" status of the extremity that the cuff is placed on to avoid medical and legal complications.

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# Avoid Errors in Invasive Blood Pressure Measurement

David Barbara, MD, Michael Hogan, MD, Toby N. Weingarten, MD, and Juraj Sprung, MD PhD

Accurate monitoring of a patient's blood pressure (BP) is crucial to the safe conduct of any surgical procedure. This chapter focuses on invasive arterial BP monitoring and some of the common errors associated with inaccurate readings.

For an arterial monitoring system to provide an accurate reading of the measured waveform, it must have an appropriate natural frequency and damping (Fig. 102.1A). Briefly, each measuring system has a natural frequency about which it oscillates. This natural frequency is directly proportional to the following:

- Stiffness of the transducer tubing and transducer diaphragm
- Diameter of the transducer tubing
- Inverse of catheter length
- Inverse of transducing tubing fluid density

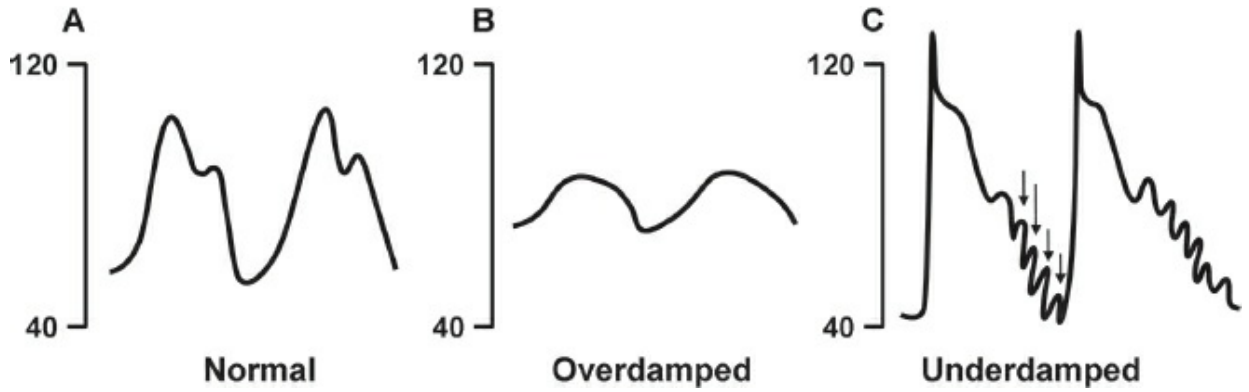


**Figure 102.1.** Arterial blood pressure (BP) waveform tracings. **A:** Normal. **B:** Overdamped tracing, causing underestimated systolic BP and overestimated diastolic BP. **C:** Underdamped tracing, causing overestimated systolic BP and underestimated diastolic BP. Extra nonphysiologic waveforms on the underdamped tracing reflect hyperresonance of the measuring system (arrows).

Ideally, the natural frequency of an arterial monitoring system should be >24 to 30 Hz. If the frequency of the measured pressure wave approaches the natural frequency of the system, the system resonates and distorts the measurements by excessive

amplification of the incoming waveform. This may overestimate the systolic BP by as much as 25% and underestimate the diastolic BP by 10% (with the mean BP not being affected). Appropriate damping counteracts this phenomenon and can compensate for a low natural frequency in an arterial monitoring system.

Several problems may result from this interaction between the natural frequency and damping parameters. Overdamping decreases the frequency response, which results in underestimating the systolic BP and overestimating the diastolic BP (Table 102.1 and Fig. 102.1B). Underdamping (especially at higher heart rates) may result in hyperresonance and overestimation of the systolic BP, underestimation of the diastolic BP, and can result from several causes (Table 102.1). Underdamping may also cause the appearance of additional, small, nonphysiologic pressure waves on the tracing (Fig. 102.1C, arrows). Slow degradation in the dynamic response also may occur over time (decrease in the natural frequency or increase in the damping coefficients), causing overdamping. Fortunately, this problem can often be rectified with periodic manual flushing of the system.

**Table 102.1 ■ Causes of and Resulting Inaccuracies From Overdamped and Underdamped Arterial Lines**

| Condition | Inaccuracies Produced in Arterial Line Reading | Causes |
|---|---|---|
| Overdamping | 📖📖📖↑ Systolic BP reading<br>↓ Diastolic BP reading | Kinked catheter or transducing line<br>Loose connections in transducing line<br>Air in transducing line<br>Arterial spasm<br>Clot in transducing line or arterial catheter<br>Inadequate flushing of transducing line<br>Stopcock partially closed on transducing line<br>Use of excessive number of stopcocks in transducing line |
| Underdamping | 📖📖📖↓ Systolic BP reading<br>↑ Diastolic BP reading | Long transducing lines (>1.4 m)<br>Small diameter tubing (<1.5 mm internal diameter) |

Arterial cannula too large for vessel
Use of compliant transducing tubing

Problems within the system that lead to inaccurate measurements are usually due to the mechanical connection components (i.e., the catheter, fluid-filled tubing, or the stopcock). To prevent these mechanical problems, several steps should be followed.

- Choose the proper size arterial cannula (20G for radial or brachial, 18G for femoral).
- Optimize the frequency response of the measuring system by using tubing that is short (maximum length, 1.2 m), appropriately wide (1.5 to 3.0 mm internal diameter), and rigid.
- Minimize the use of stopcocks in the transducing line. Keep the tubing, stopcocks, and domes free of bubbles and clots. Avoid kinks in the tubing.
- If arterial BP is overdamped:
  - Try flushing the line.
  - Keep the entire mechanical coupling system continuously flushed with 1 to 3 mL/hour of normal saline to prevent development of clots.
  - Ensure the flushing system of the arterial line is adequately pressurized and functioning.
- If arterial BP exhibits resonance:
  - Use a resonance overshoot eliminator (commercially available product that adds damping).
  - Temporarily place a small air bubble in the system (do not forget to withdraw it immediately after measurement is accomplished). The bubble (0.1 to 0.2 mL air) can be inserted at the transducer stopcock with a small syringe (1 mL) and serves as a damper. This serves to "correct" the erroneous reading to the actual BP, but this is a controversial technique that not all experts recommend.
- Use a transducer system with the highest possible natural frequency response (i.e., shorter transducer tubing and larger transducer tubing diameter).
- Zero the arterial line to atmospheric pressure to provide a reference point. By convention, the transducer is placed in level with the right atrium or midaxillary line. For a sitting patient, some experts recommend that the transducer be placed at the level of the brain (i.e., tragus). Check frequently for improper zeroing and drift. Every time the measured BP is "out of expected range," quickly verify correct transducer height and then check that the transducer is zeroed (open the transducer to air and see if the baseline goes to zero; waiting for the digital reading to confirm the proper "zeroing" numerically is not necessary). Readjust the transducer height after every change in patient positioning.

Anesthesiologists often have no control over the inherent natural frequency and

damping coefficients present in monitoring systems. Furthermore, clinical circumstances sometimes require longer extension tubing or extra stopcocks for blood sampling and flushing. In these circumstances, the fast-flush test, described in Figure 102.2, is a convenient bedside method for determining system performance parameters. The damping coefficient may be determined as described in the legend of Figure 102.2.

In clinical practice, if there are two different BP readings (e.g., noninvasive versus invasive, left arm versus right arm) and/or two different waveforms (e.g., femoral versus radial), it may be difficult to discern which pressure is most accurate. The phenomenon of distal pulse amplification can affect the morphology and detail of the arterial waveform and can often give important diagnostic information. In short, pressure waveforms recorded simultaneously from different arterial sites will have different morphologies. This difference is due to the physical characteristics of the vascular tree—specifically, impedance and harmonic resonance. As the arterial pressure wave travels toward the periphery, the arterial upstroke steepens, the systolic peak increases, the dicrotic notch appears later, the diastolic wave becomes more prominent, and the end-diastolic pressure decreases. This results in higher systolic pressure, lower diastolic pressure, and wider pulse pressure. However, despite these differences, the mean arterial pressure between central and peripheral readings should correlate despite distal pulse amplification. In addition, a substantial difference between peripherally measured BP (i.e., radial artery) and more centrally measured BP (i.e., femoral artery or aorta) may temporarily exist in specific conditions such as after discontinuation of cardiopulmonary bypass. Ultimately, clinical judgment must be used, and typically the pressure that can more adversely affect outcome (e.g., hypotension in a patient with critical aortic stenosis) is the one that should typically be “believed.”

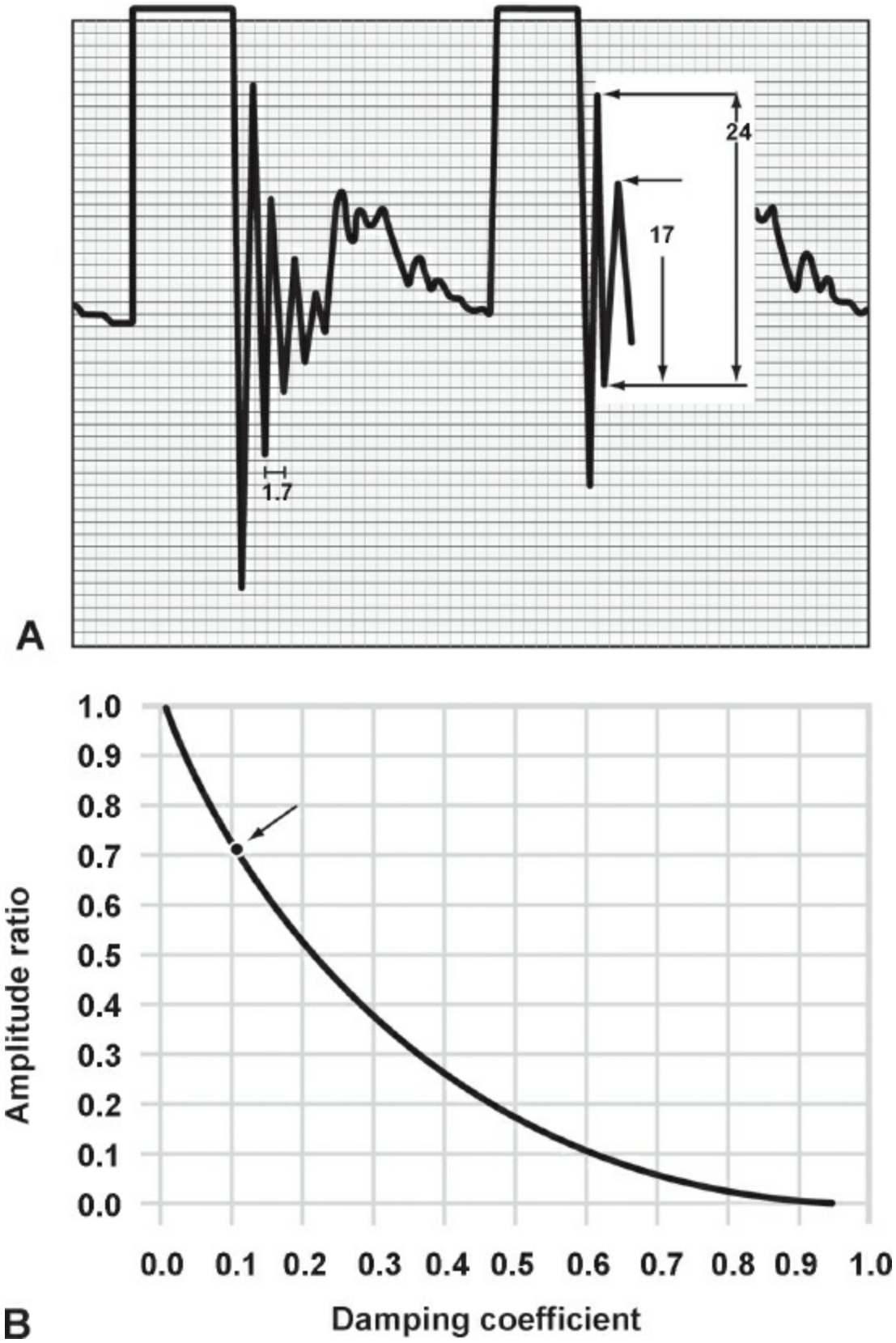


**Figure 102.2.** Clinical measurement of natural frequency and damping coefficient with the fast-flush test. **A:** Two square-wave fast-flush artifacts interrupt an arterial pressure waveform recorded on standard 1-mm grid paper at a speed of 25 mm/second. Natural frequency is determined by measuring the period of one cycle of adjacent oscillation peaks (1.7 mm). The damping coefficient is determined by measuring the heights of adjacent oscillation peaks (17 and 24 mm). From these measurements, a natural

frequency of 14.7 Hz (1 cycle/1.7 mm × 25 mm/s = 14.7 cycles/second) and an amplitude ratio of 0.71 may be calculated. **B:** The amplitude ratio corresponds to a damping coefficient of 0.11, suggesting overdamping (an optimally damped system has a damping coefficient of 0.6 to 0.7). (From Mark JB. Atlas of Cardiovascular Monitoring. 1st ed. New York: Churchill Livingstone; 1998:112–113. Used with permission.)

During the course of a surgery, if significant hypotension occurs, the following steps should be performed, with the "benefit of the doubt" being given first to true hypotension and not immediately assuming an erroneous BP:

) **Look for other clinical signs that may coincide with true hypotension:**

- Ongoing bleeding
- Laparoscopic/thoracoscopic insufflation—impeded venous return
- Mechanical (surgical manipulation) compression of venous return
- Poorly palpable peripheral pulses
- Concomitant tachycardia as a compensatory response to hypotension
- Electrocardiogram changes (e.g., atrial fibrillation/flutter, ventricular tachycardia, supraventricular tachycardia, severe bradycardia, signs of myocardial ischemia)
- Loss of previously present reliable pulse oximeter waveform
- If a pulmonary artery catheter is present, concomitant decrease in pulmonary artery pressures (or a severe increase in pulmonary artery pressures if a reaction to a drug such as protamine is a consideration)
- Urticaria, fever, bronchospasm, or other signs of anaphylactic or anaphylactoid reactions
- Sudden decrease in end-tidal $CO_2$ (indicates low cardiac output and poor perfusion of pulmonary vasculature)
- Poor capillary refill (>2 to 3 seconds), which can be examined on any readily accessible portions of a patient given a particular operation

) **Verify the observed hypotension of the arterial line with another modality such as a BP cuff.** If a substantial discrepancy exists:

- Verify the transducer line is not kinked, a stopcock is not inadvertently turned off to the transducing line, or personnel are not leaning on the artery/limb being transduced.
- Immediately verify correct transducer position. Having the transducer positioned below the desired reference point falsely elevates BP readings and vice versa. The magnitude of this error is the difference in hydrostatic pressure between the patient and the transducer (1 mm Hg = 1.3 cm $H_2O$).

) **Verify the "zero" of the transducer.** Open the stopcock to air and inspect the monitor screen to ensure that the pressure trace overlies the zero pressure line on the

screen and that the digital pressure value equals zero. If the pressure is not equal to zero, baseline drift of the electrical circuit's transducer has occurred and the system must be re-zeroed.

- **Double-check the integrity of all system components** (electrical plug-ins, loose attachments, etc.).

In addition to treating the hypotensive patient, anesthesiologists should consider the following prior to or in conjunction with performing the above steps:

- Notify the surgeon and interrupt the surgical course until the problem is identified (assuming there is no obvious bleeding source). In extreme cases, ask the surgeon to palpate some of the abdominal or thoracic vessels if any are accessible.
- Do not immediately assume an overdamped waveform or erroneous BP reading, because the "overdamped waveform" and/or "erroneous BP reading" may in fact be true hypotension.
- Be aware that severe "hypotension" on one extremity may reflect severe peripheral vascular disease (subclavian stenosis, aortic dissection, etc.), and that in these patients noninvasive BP assessments should be made on both extremities before deciding which side will be used for placing the invasive arterial line.

## TAKE HOME POINTS

- Measuring systems oscillate around a natural frequency, which can resonate and amplify a measured waveform, if the frequencies are close. Damping can counteract this, but be aware that a variety of factors can cause either underdamping or overdamping.
- Problems within the system that lead to inaccurate measurements are usually due to problems with the mechanical connection components.
- Pressure waveforms recorded simultaneously from different arterial sites will have different morphologies. This difference is due to the physical characteristics of the vascular tree—specifically, impedance and harmonic resonance.
- The mean arterial pressure between central and peripheral readings should be roughly the same.
- If the blood pressure measurement decreases suddenly, do not assume an overdamped waveform, because the "overdamped waveform" may be true hypotension.

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# How, Why, and When to Use Brain Function Monitors

Izumi Harukuni, MD

Brain function monitoring during anesthesia has always seemed a bit ironic to many practicing anesthesiologists—the brain is the target organ for anesthetics, of course, but very little is actually known about how the anesthetic agents produce unconsciousness. Despite that, brain function monitors provide anesthesiologists with information derived from a variety of physiologic cerebral parameters including electroencephalogram, regional cerebral oxygen saturation, and cerebral blood flow velocities that can be used to optimize perioperative outcomes in certain clinical settings. However, there are two caveats to the use of intraoperative brain function monitoring. The first and most important is that, regrettably, currently available brain function monitors **cannot directly measure or assess intraoperative awareness**. Secondly, the clinical effectiveness of brain function monitors has not been strong enough to justify the cost for using them in routine clinical settings.

Let us consider further the issue of awareness. At present, intraoperative awareness is most definitively evaluated by asking patients about explicit perioperative events postoperatively. This unfortunate complication reportedly occurs in 1 to 2 out of 1,000 general anesthesia cases and it is highly associated with posttraumatic stress disorder (PTSD). The American Society of Anesthesiologists (ASA) Closed Claim Project reported that claims of intraoperative awareness represent 2% of all closed claims. The majority of patients with awareness were female, ASA patient status score 1 to 2, less than 60 years old, and having elective surgery. This contradicted the previously reported high-risk populations such as trauma surgery, cesarean section, and cardiac surgery. The majority of events were associated with inadequate anesthetic agent, equipment malfunction or misuse, IV infiltration, and medication errors. Some "awareness" events have been reported by patients who received sedation. These cases may represent communication discrepancies between the anesthesia provider and patient or a failure of an accurate informed consent. The discrepancy between a patient's expectation and their experience can cause significant distress and persistent

psychological sequelae. Unfortunately, these factors will not be reliably eliminated by the use of a brain function monitor.

## What Is a "Depth of Anesthesia" Brain Function Monitor?

Traditionally, the depth of anesthesia is measured with end-tidal inhalational anesthetic concentration or combined with other physiologic parameters that are affected by anesthesia. These parameters include blood pressure, heart rate, purposeful movements, pupillary responses, lid reflex, sweating, and tearing. Since 1996, devices monitoring the depth of anesthesia using processed electroencephalogram have been available for clinical use. Currently, there are seven devices on the market including BIS (Covidien, Boulder, CO), which was the first device to be approved by FDA, SedLine (Massimo Corp, Irvine, CA), E-Entropy (GE Healthcare, Wauwatosa, WI), Narcotrend (Narcotrend-Gruppe, Hanover, Germany), Cerebral State Index Monitor (Danmeter-Goalwick, Odense, Denmark), Neurosense(Neurowave Systems Inc, Cleveland, OH), and aepEX (Medical Device Management Ltd, Essex, UK). All of these monitors measure processed electroencephalogram (EEG) using a proprietary algorithm and generate a dimensionless index typically scaled from 0 (isoelectric EEG) to 100 (awake), or A (awake) to F (very deep hypnosis) (in Narcotrend). The recommended intraoperative value is generally 40 to 60 or D0 to D2 (in Narcotrend). Further information regarding the processing algorithm is well summarized in one of the suggested readings.

## What Are the Benefits and Limitations?

A Cochrane review of 36 randomized controlled studies concluded that BIS-guided anesthesia can reduce the risk of intraoperative awareness in high-risk patients compared to management using clinical signs as a guide of anesthetic depth. However, this effect **was not significant when compared with end-tidal gas monitoring guided management**. The authors also found that BIS-guided anesthesia improves anesthesia delivery by reducing the requirement of anesthetic agent and decreasing postoperative recovery time from deep anesthesia.

The results of early studies of brain function monitors were highly variable due to study design problems such as low power, interindividual variability, lack of consistent protocol, and variable end-points. In addition, these monitors may not always reflect a patient's clinical status due to delay in EEG-acquisition or index display and specific clinical conditions that also affect EEG signals (hypothermia, hypoglycemia, advanced age, seizures, cerebral ischemia). Most importantly, the effect of anesthesia on brain function and index values, namely the transition between consciousness and

unconsciousness as well as the balance between nociception and antinociception are not well understood.

## What Do Current Guidelines Say?

In 2006, American Society of Anesthesiologists published a practice advisory on awareness. The advisory emphasized the preoperative identification of risk factors, adherence to a preinduction checklist protocol to verify the proper functioning of IV access and equipment, use of multiple modalities to monitor depth of anesthesia and brain function monitoring. The advisory acknowledged that the brain function monitoring is not routinely indicated for general anesthesia and the decision to use it should be made on a case-by-case basis for selected patients. Once an episode of intraoperative awareness has been reported, it is crucial to speak with patients to discuss possible reasons and to offer counseling for psychological support.

In 2012, the National Institute of Health and Clinical Excellence in the United Kingdom published guidelines for the use of "depth of anesthesia monitors." They recommended EEG-based depth of anesthesia monitors as an option during general anesthetics in patients considered at higher risk of adverse outcomes including unintended awareness and excessively deep anesthesia. They also suggested considering monitors in patients receiving total intravenous anesthesia because of the inability to measure end-tidal anesthetic concentration. The guidelines stated that a higher risk of unintended awareness can occur with patients who have a history of high opiate or alcohol use, airway problems requiring longer time for intubation, previous accidental awareness, required muscle relaxants, older patients, and poor cardiac reserve.

Although it does not yet appear in formal guidelines, there is growing information to suggest that patients with a lower "BIS number" are at higher risk of having postoperative delirium. So, for patients with known high risk of delirium, such as elderly patients, there are reasonable data to suggest that the anesthesiologist should place a BIS monitor and deliver an anesthetic with a target range of 50 to 60, rather than 40.

## Our Personal Practice

As stated, the use of intraoperative brain function monitoring is clinician-specific and case-specific. The authors and editors have a range of practice relating to brain function monitors—we all typically and routinely use a brain function monitor for cases with a recognized "high risk of intraoperative awareness."

We also use intraoperative brain function monitoring in older patients who appear not to tolerate anesthesia from a cardiovascular viewpoint, and in patients with

hypertension who appear to be requiring large amounts of anesthesia—in other words, to help "sort out" the physiology—are you giving anesthesia to treat the possibility of increased or decreased anesthesia needs or are you giving anesthesia in response to the pre-existing physiology and pathology of the cardiovascular system?

But we also use brain function monitoring in cases in which the patient is at risk for cerebral ischemia, such as spinal cases under total intravenous anesthesia (TIVA), and other "subspecialty cases." For example, the neuroanesthesiologists in the editorial group find the BIS monitor most helpful in patients having tumor resection with stereoelectroencephalogram (SEEG) monitoring. SEEG is obtained with depth electrodes and is used to elucidate epileptogenic foci in and adjacent to "eloquent areas." The SEEG signals are highly sensitive to anesthetics and GABA agonists (benzodiazepines and propofol) are avoided. A low dose (around 0.5 MAC) of sevoflurane is typically used for the anesthetic. Because these patients use antiepileptic drugs at baseline, they are at risk for intraoperative awareness. A BIS value that may portend intraoperative awareness warrants consideration of an increase in sevoflurane concentration after input from the neurosurgeon and neurophysiologist.

Finally, we usually apply the brain function at the start of the case, but do not hesitate to initiate use during the middle of a case if we think it will point us in the right clinical and anesthetic direction.

## The Future?

Recent research on the neuronal mechanism of the phenomenon of consciousness suggests that the final common pathway of loss of consciousness for all groups of anesthetics lies in a loss of connectivity between parietal and frontal regions of the brain. Recent advances in EEG analysis may provide monitoring of connected consciousness as well as responsiveness but these techniques are very complex and not yet refined for routine clinical use.

A newer generation of indices attempt to measure the antinociception component of anesthesia that may not be well reflected in brain monitor indices by themselves. Incorporating parameters such as autonomic responses, electromyographic variability, demographic data, and the presence of surgical stimulation may further improve the evaluation of consciousness during anesthesia.

### TAKE HOME POINTS

- Intraoperative awareness is a rare but devastating complication during anesthesia.
- Risk factors for intraoperative awareness include:

a. Patients with history of high opiate or alcohol use

b. Difficult airway or long intubation time
c. Prior history of accidental awareness
d. Use of muscle relaxants
e. ASA Physical status IV and V
f. Intraoperative hemodynamic instability
g. Total intravenous anesthetic

- It is imperative to perform a preoperative evaluation focused on identifying risk factors for awareness, a preoperative check to ensure the proper functioning of IV access and equipment, and use multiple modalities to monitor depth of anesthesia.
- Brain function monitoring is not routinely indicated for general anesthetics. The decision to use it should be made on a case-by-case basis considering patient and surgical risk factors.
- EEG-derived brain function monitors may reduce the incidence of intraoperative awareness, improve short-term outcomes, and reduce cost. However, major studies have shown highly variable efficacy.
- Once an episode of intraoperative awareness has been reported, it is crucial to speak with patients to discuss possible reasons, and to offer counseling for psychological support.

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# Do Not Improvise Techniques to Warm Patients—Use Warming Devices Only as Per Manufacturers' Recommendations

Jeff Mueller, MD FASA

Any review of patient warming must begin with a review of the principles of normal thermoregulation and monitoring standards.

In human beings, thermoregulatory mechanisms maintain a core body temperature of approximately 37°C, with a "normal" range of only 0.2°C (circadian and menstrual influences also cause up to a 1.0°C variation of the core temperature). The body-temperature control system operates via an elegant feedback loop. Widely distributed, distinct heat and cold receptors send afferent thermal input via nerve fibers to the central nervous system and more specifically to the hypothalamus, which is the primary thermoregulatory control center. Hyperthermia results in efferent hypothalamic output that causes cutaneous vasodilation and sweating. Hypothermia generates hypothalamic outputs leading to vasoconstriction, shivering, and, in infants, nonshivering thermogenesis. Overall, the most important mechanism for maintaining normal human body temperature is behavior. The obvious inability of anesthetized patients to add clothing and blankets or adjust the thermostat removes their most important defense against hypothermia.

It has long been recognized that metabolic functions deteriorate when internal temperatures are abnormal and also that both regional and general anesthesia impair thermoregulatory mechanisms. This knowledge is reflected in the American Society of Anesthesiologists' Standards for Basic Anesthetic Monitoring, which state that "during all anesthetics, the patient's oxygenation, ventilation, circulation, and **temperature** should be continually evaluated" and that "every patient receiving anesthesia shall have temperature monitored when clinically significant changes in body temperature are intended, anticipated or suspected."

Core-temperature monitoring sites include the tympanic membrane, pulmonary artery, nasopharynx, and the distal portion of the esophagus. Whether the bladder is a site permitting accurate measurement of core temperature depends upon urine flow. Core

temperature may be measured in the bladder if urine flow is high; however, if urine flow is low, the measurement made may reflect peripheral temperature.

## Complications of Hypothermia

Evidence suggests that perioperative hypothermia contributes to increases in surgical-wound infections, intraoperative blood loss, transfusion requirements, myocardial ischemia, and arrhythmias. The cardiac risks are highlighted in perioperative guidelines published by the American College of Cardiology and American Heart Association. Hypothermia has also been shown to slow the metabolism of anesthetic drugs and to increase the duration of postanesthetic recovery. The postoperative sensation of cold and shivering is unpleasant for patients and is recalled by some as causing more discomfort than was caused by surgery.

## The Pathophysiology and Physics of Hypothermia

Perioperative hypothermia is caused when a patient is in a relatively hypothermic environment while simultaneously experiencing a loss of thermoregulatory control.

The difference between the patient temperature and the operating room ambient temperature drives heat transfer from the patient to the surrounding environment. There are four modes of heat transfer: **radiation, convection, evaporation, and conduction**. All play some role in heat loss in surgical patients; the greatest amount occurs by radiation.

Both general anesthesia and regional anesthesia impair thermoregulation. General anesthesia inhibits thermoregulation in a dose-dependent manner. Cold-response thresholds are significantly reduced, and warm-response thresholds are slightly elevated. Anesthesia increases the above-mentioned threshold range from 0.2°C to 2° to 4°C. The initial phase of anesthesia is dominated by a rapid redistribution of heat from the core to the periphery due to vasodilation. During the next 2 to 4 hours, core temperature decreases, albeit at a slower rate, primarily because heat loss exceeds metabolic heat production. Neuraxial anesthesia disrupts thermoregulatory mechanisms by blocking sensation and neural transmission, causing vasodilation without inducing any compensatory mechanisms. Thus, a combination of anesthesia-induced thermoregulatory dysfunction and an unfavorable thermal environment result in heat loss and hypothermia in surgical patients.

## Preventing Hypothermia

All members of the patient's surgical care team are responsible for preventing perioperative hypothermia, beginning with care in the preoperative area and extending

into the operating room by maintaining the ambient room temperature at a reasonable level. A normal and comfortable room temperature is required during patient transport into and out of the operating room. For the comfort of the care team, it **may** be reasonable to lower the ambient temperature once the patient is covered, the surgical site is prepped, and warming devices have been applied. **But remember, the operating room ambient temperature is the most important determining factor of heat loss!**

In addition to ambient temperature management, warming devices can be used to prevent hypothermia. Less than 10% of metabolic heat is lost through the respiratory tract. Therefore, active heating and humidification of ventilator gases has minimal impact on core-temperature maintenance. The temperature of intravenous fluids is also a consideration. Since the temperature of intravenous fluids and blood products cannot significantly exceed body temperature, actively heating patients with fluid warmers is not possible. However, heating of fluids is required to **prevent heat loss** when large volumes are administered. Preventing cutaneous heat loss is also necessary. Passive insulation, such as using blankets, may be adequate for small operations. More extensive operations require active cutaneous warming, using forced-air or circulating-water devices. Forced-air warming systems consist of a thermostatically controlled electric air heater, a fan system, and an inflatable blanket with perforations on the patient side. The fan system blows heated air into the blanket and warming then occurs by convective heat transfer.

## Preventing Patient Injury While Preventing Hypothermia

Warming devices should always be operated according to the manufacturer's instructions. Improper use can result in excessive heat and burns. The use of forced-air blankets should be avoided in areas affected by peripheral vascular disease or other causes of significantly impaired circulation, especially vascular cross clamping. These warming devices should be used only with the appropriate, specified blanket. The heated forced-air output should not be used in any other way since improper use has been documented to cause thermal injury to the patient. In addition, operating-room warming cabinets must be operated at a safe temperature. Burns can also occur when heated intravenous fluid bags or blankets are used as positioning aids. **Items pressed against the patient may reduce perfusion in the contact area and cause burns at temperatures that would otherwise be safe.** All operating rooms should follow a rigorous plan for monitoring and maintaining safe temperatures in warming cabinets. An analysis of the American Society of Anesthesiologists closed claims database revealed that intravenous fluid bags or bottles were the most common cause of claims related to operating-room burns; the second most common cause was warming devices, such as

heating pads and blankets. Remember that any warming device can potentially harm anesthetized patients, who cannot sense excessive heat.

## TAKE HOME POINTS

- Regional and general anesthesia impair thermoregulation.
- Hypothermia can harm patients by impairing coagulation, increasing infection rates, and contributing to myocardial stress.
- Patients can be kept normothermic when appropriate measures are instituted throughout the perioperative period.
- Misuse of warming devices can cause thermal injury.
- Do not use heated bags of crystalloid solution to warm patients!

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# Transesophageal Echocardiography: Contraindications, Complications, and Misinterpretations

Andrew Young, MD and Andrew Oken, MD

With increasing patient complexity and cardiac comorbidities, the use of intraoperative transesophageal echocardiography (TEE) has become more prevalent. While the utility of TEE in the cardiac operating room (OR) is proven, it is important to carefully consider the contraindications for probe placement as the complications can be fatal. After appropriate consideration of the relative risks and benefits, a relatively quick assessment of management-changing intraoperative cardiac findings such as pericardial effusion, and left ventricular (LV) function, filling and valve characteristics may be accomplished within minutes. Practice Guidelines for Perioperative Transesophageal Echocardiography as referenced below and jointly written by the ASA/SCA provides an excellent starting point for broadening the clinicians' education in TEE. In addition, there are several pitfalls to be aware of when interpreting live images that can lead anesthesiologists to the wrong conclusion with potentially significant ramifications.

## Probe Placement

When considering whether the patient may be appropriate for TEE probe placement, first evaluate for absolute and relative contraindications. **Absolute contraindications to TEE include patient refusal, esophageal obstruction, unrepaired tracheoesophageal fistula, perforated viscous, esophageal pathology, and active upper GI bleed.** Relative contraindications may also sway the relative risk–benefit equation and should be considered. **These include cervical spine disease, head and neck or thoracic radiation, coagulopathy, and swallowing abnormalities.** After evaluating for these contraindications the patient should be formally consented for the procedure preoperatively unless in an emergency. Also consider obtaining consent in advance for complex patients because, if they become unstable intraoperatively, it can be cumbersome or impossible to obtain consent while the patient is anesthetized.

During probe placement, take care to advance the probe slowly and maintain a

midline orientation. A forward jaw displacement and head tilt may facilitate esophageal passage; a slight anteflexion may be helpful as well. Take care to not injure any teeth in this process, or attempt to push the probe past any obstruction. Remember, as with any invasive procedure, positioning and finesse are more important than brute force. If the probe perforates the esophagus, potentially fatal mediastinitis may ensue. Since there are numerous important structures adjacent to the esophagus, a perforation is a complication every anesthesiologist should actively avoid with extra probe lubrication and optimal positioning and ample clinical experience. Patients should be reasonably well informed of these risks during the consent process before surgery, though in a life-threatening emergency consent is not required.

After the probe is placed, take care to "freeze" the image when not using the probe. Because ultrasound probes use very high frequencies to achieve excellent tissue resolution and penetration, the vibration of water molecules causes heat. This heat may potentially cause thermal injury to adjacent tissues. When freezing the image, there are no sound waves produced by the probe, thus no heat created in surrounding tissues. We suggest leaving the image frozen rather than turning off the machine completely as many machines require several minutes to load, potentially delaying diagnosis in the event of acute hemodynamic instability.

## Image Interpretation

Once the probe is successfully placed in the esophagus, there are several pitfalls to avoid when interpreting images. Ultrasound images are based upon the time required for an ultrasound wave to reflect from an object and the strength of the reflection. Many variables affect the signal including density of the medium, tissue type, angle of measurement, signal frequency, and range of processing. Color Doppler can be used to assess heart valve regurgitation but it is important to appreciate the fundamental ultrasound principles that change the measurement. Doppler shift is the observed shift in frequency of reflected ultrasound waves, which is related to the relative velocity of the moving object. Importantly, this Doppler shift is measured based on a linear axis set by the operator, so if the axis is aligned obliquely with a jet of ejecting blood, the Doppler shift may appear falsely decreased, causing the operator to underestimate the velocity of blood. This can be avoided by ensuring that the Doppler axis is optimally aligned with the valve jet. This is also impacted by the medium in which that ultrasound beam travels through from the probe to the object and back to the probe. For example, poor image quality may be due to excessive air in the esophagus or stomach as ultrasound waves do not travel well through air. Placement of an orogastric tube and suctioning prior to probe placement can help mitigate poor quality views due to excessive air.

Because of the complexity of post processing, ultrasound images may be optimized in

numerous ways to view the structure of interest. If the operator is unfamiliar with the machine it may lead to inability to capture the appropriate image. Each device requires familiarization but with time will become progressively more intuitive. Many ultrasound machines have specific software packages that aid in image interpretation for specific clinical settings. The machines can usually store ultrasound images linked to specific patients and allow these images to be output to electronic medical records for clinical purposes as well as quality tracking.

Assessment of (LV) function and filling intraoperatively is a key advantage of TEE as it provides continuous visual feedback. While obtaining echo images, it is important to consider the probe position relative to the LV axis. Foreshortening occurs when the imaging plane is oblique with the LV cavity axis and thus the cavity image appears smaller than in reality. This leads to artificially low quantification of LV volumes and thus potentially underestimates LV function. Try to image the entire LV before quantifying stroke volume to determine the best imaging plane to obtain stroke volume measurements and avoid foreshortening. This is often achieved in a standard mid-esophageal four-chamber image.

## Normal Anatomic Variants

There are several normal variants that are important to consider when evaluating cardiac anatomy. The embryologic remnant of the Eustachian valve may be seen at the junction between the right atrium and inferior vena cava and appears as a linear structure and maybe misinterpreted as a thrombus or vegetation. Other potentially distracting structures include the crista terminalis and moderator band in the right ventricle. The crista terminalis is a ridge of muscle that projects into the right atrium from the junction of the right atrium and superior vena cava and runs toward the inferior vena cava, and is best seen in the midesophageal bicaval view. In addition, another embryologic remnant called the Chiari Network may appear as delicate as mobile filamentous structures arising from the Eustachian valve and could be potentially misinterpreted as vegetation. Another normal structure that may be misinterpreted as a thrombus is the "Coumadin ridge," a normal structure that is formed at the intersection of the left atrial appendage and the insertion of the left upper pulmonary vein. Note that thrombi are typically homogeneous, reasonably well demarcated, and oval or spherical in structure.

Myxomas are the most common intracardiac tumor and commonly arise from the atrial septum and may involve the fossa ovalis. The atrial septum can also become lipomatous and develop a characteristic "dumbbell" appearance. The septum's fixed position can be used to help differentiate it from classically mobile spherical or ovoid myxomas. These may be difficult to distinguish from thrombi, though thrombi typically

have a layered appearance compared to a myxoma. In addition, myxomas typically have a fibrous stalk from which they emanate. Given the potential clinical uncertainty in this scenario, heparin drips are commonly initiated to facilitate thrombus dissolution. With interval TEE examinations, thrombi will characteristically "melt away," while intracardiac tumors will not be affected by systemic heparinization.

## TAKE HOME POINTS

- Be careful when placing the TEE probe—use gentle and even pressure and be aware of the risk of perforation
- Consider obtaining consent in advance for unstable or potentially unstable patients who may benefit from TEE intraoperatively
- Be aware of the "foreshortening" concept for LV function and Doppler shift principles when examining regurgitant valves
- Recall that there are several normal anatomic variants that may be misinterpreted as intracardiac pathology

## Suggested Readings


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# Scavenging Waste Gases Is Perhaps the Only Action We Take That Benefits Us but Not the Patient

Terrence L. Trentman, MD

Why scavenge waste anesthetic gases? Since the early days of the specialty, anesthesia providers have been challenged with minimizing the risks associated with volatile anesthetics. Ether and cyclopropane were known to cause explosions, and by the 1960s serious questions had arisen with regard to possible mutagenicity, carcinogenicity, and teratogenicity of the volatile anesthetics. Because volatile anesthetics are likely to remain ubiquitous in clinical practice, anesthesia providers must be aware of the following issues: the history behind current anesthetic waste gas scavenging practice; the recommended limits for trace gas levels issued by the National Institute for Occupational Safety and Health (NIOSH); the real risks of teratogenicity; the mechanics o f scavenging systems, including open versus closed interfaces and active versus passive gas-disposal assemblies; sources of exposure to waste gas; and the risk of obstructions in scavenging systems.

## Chronic Exposure to Waste Gases

Studies done in the 1960s on the risks of chronic exposure to waste anesthetic gases yielded conflicting results. A human study suggested an increased incidence of spontaneous abortion among female anesthesiologists, and an animal study showed that high concentrations of nitrous oxide could cause skeletal deformities in offspring. Subsequent publications supported the idea that waste anesthetic gases put anesthesia providers at risk for adverse health effects. In the 1970s, NIOSH recommended that waste anesthetic gases be scavenged and set recommended acceptable waste gas levels (Table 106.1). However, both prospective and epidemiologic studies conducted in the 1980s and 1990s have shown that when scavenging is used to reduce amounts of volatile anesthetics to trace amounts, the waste gases pose no risk of adverse health effects. Also, health risks are not associated with short-term clinical exposure to potent volatile agents, such as isoflurane or sevoflurane given to a patient during surgery.

Experimental nitrous oxide exposure has been associated with animal reproductive abnormalities; however, these conditions do not exist for workers in the clinical environment in which scavenging is present. Of note, NIOSH transmitted its recommendation to the Occupational Safety and Health Administration (OSHA) in 1977. Since that time, OSHA has not taken the necessary steps to promulgate the standards, but it has published technical instructions regarding waste gases. The Joint Commission (TJC) has recommended that each anesthesia machine be equipped with a scavenging system and that monitoring be carried out. In this day and age in the United States, an anesthesia provider would never be asked to do an inhalational anesthetic case without the presence of a scavenger—TJC wouldn't allow it. They even require scavenging for nitrous oxide for labor analgesia.

## Scavenging Systems

An anesthesia provider can use several methods to minimize the concentrations of anesthetic gases in the operating room environment. These methods include ensuring a tight mask fit, flushing into the waste gas system rather than the room, turning gas flow off at the end of each case, carefully filling vaporizers using a keyed filler rather than a funnel, and using a cuffed endotracheal tube when possible. In addition, a leak test should be done routinely on both the high- and low-pressure components of the anesthesia machine. **Most important is the presence of a properly functioning waste-gas scavenging system.**

A waste-gas scavenging system has five components (Fig. 106.1): the gas-collecting assembly, the transfer means, the scavenging interface (open vs. closed), the gas-disposal assembly tubing, and the gas-disposal assembly (active vs. passive). Excess gas from the patient is collected via the ventilator relief valve or the adjustable pressure limiting (APL) valve. Collected gas is transferred to the scavenging interface via short, rigid (nonkinking) tubing. If obstruction of the tubing occurs at the transfer means, patient barotrauma can result as this portion of the scavenging system is proximal to the pressure relief capability of the scavenging interface.

**Table 106.1 ■ National Institute for Occupational Safety and Health Trace Gas Recommendations, 1977**

| Anesthetic Gas | Maximum Concentration (ppm) |
|---|---|
| Agent alone | |
| Halogenated | 2 |

| | |
|---|---|
| Nitrous oxide | 25 |
| Combined halogenated and nitrous oxide | |
| Halogenated agent | 0.5 |
| Nitrous oxide | 25 |

Adapted from U.S. Department of Health, Education, and Welfare. Criteria for a Recommended Standard: Occupational Exposure to Waste Anesthetic Gases and Vapors. Washington, DC: U.S. Department of Health, Education, and Welfare; 1977.

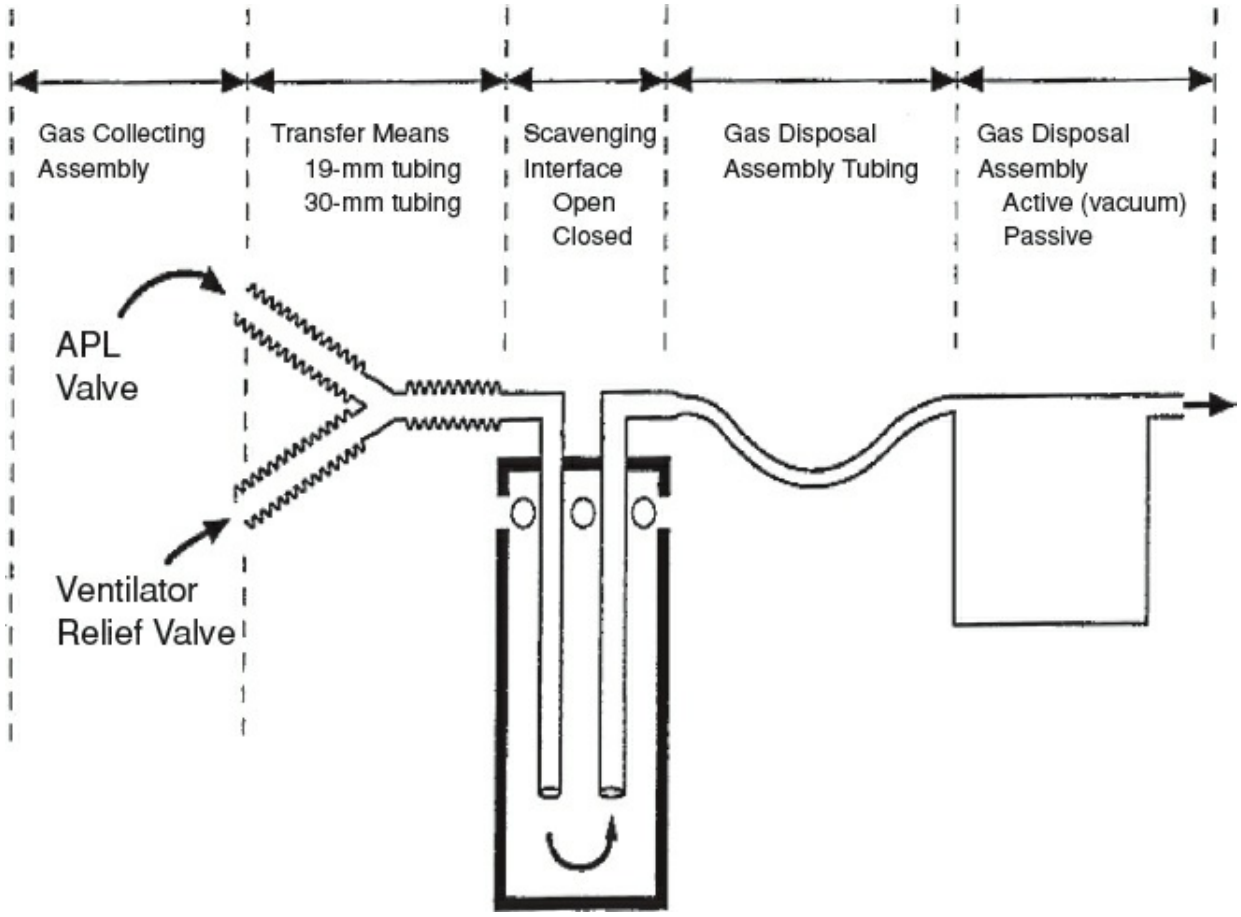


**Figure 106.1.** Components of a scavenging system. APL, adjustable pressure limiting valve. (Reproduced with permission from Barash PG, Cullen BF, Stoelting RK, eds. Clinical Anesthesia. 5th ed. Philadelphia, PA: Lippincott Williams & Wilkins; 2006:589.)

The scavenging interface can be of two types: open or closed. An open system is valveless and is essentially a canister open to the atmosphere. Gas from the transfer means tubing is delivered to the bottom of the canister which serves as a reservoir. This arrangement prevents excessive negative- and positive-pressure build-up within the system. However, an active gas-disposal assembly (central vacuum) is necessary to ensure that waste gases stored in the reservoir (canister) do not escape into the room.

The reservoir should be large enough to handle a variety of gas flow rates and gas surges. Some open systems rely upon the user to regulate the vacuum by adjusting a vacuum control valve.

Closed scavenging interfaces use valves to communicate with the atmosphere. A positive-pressure relief valve is necessary to protect the system from excess downstream pressure. The positive-pressure relief valve will open to room air if an obstruction occurs between the scavenging interface and the gas-disposal assembly. If the closed scavenging interface uses a passive gas-disposal assembly, only a positive-pressure relief valve is necessary. In this arrangement, the pressure from the waste gas itself moves the gas toward the disposal assembly, and neither a reservoir bag nor a negative-pressure relief valve is required.

When an active (e.g., central-vacuum) gas-disposal assembly is in place, a negative-pressure relief valve is necessary in the closed scavenging interface. This prevents excessive negative-pressure build-up within the system by entraining room air as needed. A reservoir bag is also necessary to store, briefly, excess gases during the ventilator cycle. The vacuum control valve is adjusted so that the bag is neither under- nor overinflated. The bag will be seen to expand during expiration and deflate during inspiration.

The gas-disposal assembly tubing transfers waste gases to the disposal assembly. The appearance of such tubing should differ from that of the breathing system hoses and should resist kinking. The tubing is ideally run overhead to minimize the risk of the anesthesia machine or other equipment rolling on top of it. The gas-disposal assembly vents waste gases to a point outdoors that is remote from air intakes and people. The disposal assembly can employ a piped central-vacuum system or an active-duct system, in which fans or blowers move gases outside.

## Avoiding Mishaps

Anesthesia providers can avoid mishaps by first understanding the mechanics of the scavenging system. Although trace waste anesthetic gases do not pose health risks, the scavenging system should be visually inspected to ensure tight connections and unobstructed tubing. As noted in Figure 106.1, the scavenging system uses 19- or 30-mm tubing that can be distinguished from the 15- and 22-mm tubing of the breathing system. Unfortunately, misconnections are still possible. The use of adapters or tape to make connections should warn the anesthesia provider of a possible misconnection.

Several steps can be taken to reduce the risk of mishaps. One-hundred percent oxygen should be administered at the end of each case to wash excess gases into the disposal system. The vaporizers should be filled using a keyed filler, and the connections should be securely tightened. Use of low gas flows also reduces waste gas,

as does the use of regional and intravenous anesthetic techniques. However, minimizing waste gas should not supersede clinical considerations in choice of anesthetic technique.

Remember that, invariably, all anesthesia machines leak to some degree. Testing machines daily for leakage and servicing machines regularly minimizes this leakage. Room ventilation systems should also be inspected and serviced by the institution's facilities department. Scavenged gases should be vented to the outside and not to other rooms in the hospital in which personnel may be exposed or the gases may contribute to fire risk (e.g., machine rooms).

## TAKE HOME POINTS

- Short-term clinical (unscavenged) or long-term trace (scavenged) exposure to potent volatile agents does not cause adverse health effects.
- When scavenging systems are in place, nitrous oxide exposure has not been shown to increase reproductive risks.
- Anesthesia providers can use various techniques to minimize exposure to trace anesthetic gases including inspecting the components of the scavenging system to ensure proper connections and absence of obstruction.
- The scavenging system protects health care workers, but malfunction of the system can lead to patient injury, including barotrauma or negative-pressure injury.

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# Carbon Dioxide Absorbers Save Gas and Moisture but Create the Potential for Mechanical Hazards, Chemical Soup, or a Thermal Disaster

Michael S. Axley, MS MD and Stephen T. Robinson, MD

The main purpose of anesthesia circuits is to safely provide an efficient configuration to deliver oxygen and anesthetic gases and remove carbon dioxide ($CO_2$). If only fresh gas is going to be delivered, the required gas flows may need to be as high as two and one-half times the patient's minute ventilation (MV) to avoid rebreathing of $CO_2$. A patient with an MV of 6 L/min would require a fresh gas flow of 15 L/min. Using a $CO_2$ absorber, fresh gas flows of 500 mL/min or lower can be achieved while preventing the rebreathing of $CO_2$.

## Basic Management of Absorbers

Currently available $CO_2$ absorbents consist of soda lime (sodium hydroxide lime), potassium hydroxide–free lime, calcium hydroxide lime, and noncaustic lime. These absorbents all contain hydroxide bases as their active component. The main reactant in these absorbents is calcium hydroxide. Since it is a slow reactant, other constituents are needed to allow the conversion to occur at a sufficient rate in vivo.

**Soda Lime Reaction:**

) $CO_2 + H_2O \rightarrow H_2CO_3$ (fast)
) $H_2CO_3 + 2NaOH$ (or KOH) $\rightarrow Na_2CO_3$ (or $K_2CO_3$) + $2H_2O$ + Energy (fast)
) $Na_2CO_3$ (or $K_2CO_3$) + $Ca(OH)_2 \rightarrow CaCO_3 + 2NaOH$ (or KOH) (slow)

The $CO_2$ absorbent is on the expiratory limb of the anesthetic circuit. The chamber lies distal to the ventilator relief valve and the adjusting pressure limiting (APL) valve. Hence, exhaled gas is preferentially routed to the scavenging system before it is cleared of $CO_2$. The lower the fresh gas flow, the more rapid the consumption of absorbent.

Because the flow of expired gas is unidirectional, most of the reaction occurs in the proximal end of the absorbent chamber. As the reactant is consumed, the pH changes and the indicator in the white granules turns blue or purple depending on the dye. The distal end of the absorbent chamber begins to change in color when the reactant in the proximal end becomes insufficient to eliminate fully the $CO_2$ at lower flows. It is then necessary to change the reactant or to use higher fresh gas flows.

Caustic water and residue can build up at the base of the absorber and along the distal tubing. To avoid inadvertent obstruction to gas flow, draining the fluid periodically and following routine maintenance recommendations, as provided by the anesthesia machine manufacturer, are necessary.

## Mechanical Complications

Channeling is a condition that occurs when the gas flow through the absorbent is diverted through areas of low resistance, causing a "channel" to be formed. Gas flowing through a channel does not undergo the reaction clearing $CO_2$—hence, absorbents that form channels are less effective. More ominously, the absorbent that is exhausted or in which channeling has occurred may permit rebreathing of $CO_2$ through the circuit, with subsequent patient morbidity.

The issue of channeling is related to that of absorbent pellet size. Air flow through a mass of pellets varies inversely with pellet size; that is, larger pellets generate less resistance through the circuit. At the same time, large pellets expose less total surface area to air flow, decreasing the total surface area available to participate in the reaction that removes $CO_2$. The most commonly available pellet size for $CO_2$ absorbents is 4 to 8 mesh. "Mesh" indicates the number of openings per linear inch in a sieve used to measure the pellet particles.

Not all $CO_2$ rebreathing is related to consumption of $CO_2$ absorbent. If $CO_2$ rebreathing is detected, one should also consider alternative methods in which rebreathing can occur. Inspiratory and expiratory valves stuck in the open position can cause rebreathing. Kinked anesthesia hoses can also cause $CO_2$ rebreathing.

Improperly sealing the $CO_2$ canister can cause a leak. The leak may be caused by failing to close the canister or by a loose granule obstructing the seal. Prepackaged granules, although more expensive, may reduce this risk. Improperly placed soda lime can also obstruct flow. This has been reported to occur with prepackaged granules when the packaging was not removed before insertion into the circuit.

## Adverse Chemical Reactions

The hydroxide bases in $CO_2$ absorbents are caustic and can cause tissue damage with

skin exposure or inhalation. Persons handling these materials must take care to avoid splashing or spilling the new or used chemical. Gloves and eyewear should be worn when the canisters are moved or replaced.

In addition to removing $CO_2$ from the gas-and-vapor mixture, these strong bases may break down or degrade the potent inhaled anesthetic agents. The breakdown products differ among the various agents. Sevoflurane, upon degradation, generates a potentially nephrotoxic product called Compound A (2,2-difluoro-1-(trifluoromethyl)vinyl ether). Using fresh gas flows of 2 L/min or greater can prevent this reaction. Under circumstances in which the $CO_2$ absorbent is dehydrated, isoflurane and desflurane can be broken down into carbon monoxide (CO), with subsequent reported cases of CO poisoning.

Dehydration is an important component of breakdown—the reaction of anesthetics increases as the water content of the $CO_2$ absorbent decreases. Complete desiccation of absorbent requires exposure to dry gas at room temperature for a number of hours, that is, a fresh gas flow of 5 L/min for 24 hours.

In addition to CO or Compound A, the reaction of inhalational anesthetics with desiccated $CO_2$ absorbent can produce flammable organic compounds. In the case of sevoflurane, these by-products include methanol and formaldehyde. Further, these breakdown reactions are exothermic. The combination of exothermic reaction and flammable breakdown products can accelerate the overall cycle to the point where spontaneous combustion may occur. The combustion reaction may also consume sufficient anesthetic gas as to make maintenance of anesthesia problematic.

The desiccation of absorbent and the subsequent production of CO cannot be detected with routine anesthetic monitors. Traditional absorbents typically turn a blue-violet color when approaching exhaustion—this does not occur with desiccation. Diagnosing CO toxicity can be quite difficult when a general anesthetic has been used; symptoms such as confusion, nausea, shortness of breath, and dizziness might also be attributed to emergence from anesthesia. A co-oximetry pulse oximeter can measure arterial saturation of CO, but its efficacy in the operating room setting has not been well established.

Some experts have advocated monitoring the temperature of absorbents as a way to avoid potentially lethal outcomes. Such monitoring can be done, for example, by placing a temperature probe in the center of each canister of absorbent and sealing the edge of the canister with foam tape. Yet, what temperature cut-off signals an impending event is unclear, as the temperature of the absorbent is elevated during normal use.

Although the capnogram is not a foolproof method of determining absorbent exhaustion, the presence of an elevated inspired $CO_2$ baseline may indicate absorbent exhaustion and/or desiccation.

Absorbent manufacturers have developed products, some moist and some desiccated, that produce an insignificant amount of or no Compound A or CO. These products also produce minimal heat and minimally adsorb volatile agents. The Anesthesia Patient Safety Foundation recommends implementing policies at the institutional and departmental level "regarding steps to prevent desiccation of the carbon dioxide absorbent should they choose conventional carbon dioxide absorbents that may degrade volatile anesthetics when absorbent desiccation occurs." It also further recommends adopting some simple approaches, including turning off gas flow when the machine is not in use, changing the absorbent at regular intervals, and changing the canisters if they have been exposed to long-term fresh gas flow.

## TAKE HOME POINTS

- $CO_2$ absorbers allow for safe, economical use of anesthetic vapors.
- Anesthesia machines must be maintained to avoid leaks and obstruction of flow.
- The breakdown of anesthetic gases, particularly of sevoflurane, can lead to production of toxic byproducts and of CO.
- Desiccated $CO_2$ absorbent tends to promote adverse reactions.
- Breakdown reactions produce heat, and operating room fires can ensue under the right conditions.

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# Infusion Pumps: Get Them Going and Keep Them Going!

Richard Botney, MD and Stephen T. Robinson, MD

Drugs and fluids may be given in the hospital by a variety of means including intravenous (IV), gastric, epidural, and intrathecal routes. The most prevalent is IV, which will be the focus of this chapter. The three basic mechanisms for delivery of IV fluids and medications are gravity, peristalsis (infusion pumps), and pistons (syringe pumps). Infusion and syringe pumps are invaluable devices used to deliver fluids and medications at reliable and controlled rates. Despite substantial improvements in accuracy, reliability, and usability, there continues to be problems with IV drug delivery and administration. Medication errors occur too frequently and can result in significant patient harm by causing hypotension, hypoglycemia, respiratory arrest, and other adverse drug events (ADEs). **During the 5-year period from 2005 to 2009, the FDA received about 56,000 reports of adverse events associated with the use of infusion pumps**. The majority of these events appear to be the result of human interactions with the pumps.

The earliest devices focused primarily on ensuring that constant, accurate flow rates were achieved. To reduce the likelihood of use errors, later pump designs included a focus on human factors and the user interface. These pumps incorporated limited programming capabilities and safety was largely dependent on the user's attention to detail. The most recent devices incorporate computer technology and allow for increasingly complex operations. At the same time, they may also increase the complexity of use, potentially resulting in difficulties with setup, programming, and operation. With good design and proper use, these "smart" pumps can reduce errors. However, infusion pumps are only one part of a complex medication delivery system, and errors can arise from any part of the system. The use of computer technology in these devices means they can interact with elements of this broader system with greater potential to reduce error and improve the safety of drug delivery.

## Gravity

Gravity devices rely upon counting drops to estimate flow rates. Such methods are rarely used anymore except for simple IV fluid administration and will not be reviewed in depth here. A number of factors affect gravity-driven infusions. Flow relies upon hydrostatic pressure, and rates will change as IV bags empty or pole heights are altered. No alarms or other safety features alert the user to problems or prevent errors in flow. IV bags may empty unnoticed and require flushing of air from the IV line before continuing the infusion. With multiple IV lines in use, the wrong line can be adjusted resulting in either inadequate drug delivery or inadvertent rapid delivery of a high-risk medication such as potassium with disastrous results. Labeling each line near the flow regulator may help to reduce this risk. While gravity devices may be easy to set up and simple to use, close user monitoring is critical to reduce the likelihood of errors.

## Infusion Pumps

Current infusion pumps use peristalsis to produce fluid flow and can be programmed to deliver fluids or drugs in a wide array of units, such as mL/hr or µg/kg/min. Linear peristaltic pumps use finger-like projections to sequentially compress IV tubing against a surface, thus moving the fluid in a forward direction. Rotary peristaltic pumps use a roller mechanism to compress the tubing and so move the fluid toward the patient. Peristaltic devices are primarily used to administer drugs and fluids from a bottle or bag. They have been manufactured to handle from one to four simultaneous infusions. The portion of tubing that passes through the device must be matched to the device. Although some devices can be modified to accommodate syringes, the higher resistance associated with pulling the plunger into the barrel tends to limit such use, especially at higher flow rates. Free-flow, a problem when using bags with older pumps, has been extensively addressed. However, inadvertent delivery of a bolus is still possible when connecting or disconnecting these devices. The Joint Commission requires pumps to incorporate free-flow prevention as part of its National Patient Safety Goals. To address this problem, manufacturers routinely provide a mechanism that automatically obstructs flow if the tubing set is removed from the pump. A manual regulator on the IV tubing (e.g., roller clamp) should also be fully closed when inserting or removing tubing.

## Syringe Pumps

Syringe pumps use a screw and piston to advance the plunger into the syringe's barrel. They work by loading a syringe into an assembly of clamps and plungers and tend to be smaller and lighter than standard peristaltic pumps. The faster the screw spins, the faster the plunger is advanced into the barrel of the syringe.

Contemporary syringe pumps can be programmed to the desired flow rate. Other

parameters that can be programmed include patient weight and drug concentration. To ensure the actual flow rate matches the programmed rate of flow, the correct syringe brand and size must be specified when programming the pump. Most of these devices have sensors attached to the barrel fastener which should detect the correct syringe size. These sensors should prevent a 10 mL syringe from being programmed as a 20 mL syringe. Nonetheless, some differences in bore size among syringes of the same volume produced by different manufacturers are too small for these devices to distinguish accurately. These differences are large enough to introduce errors in the range of 5% to 10% if there is a mismatch between the actual and programmed brands.

A number of user errors can cause problems when setting up syringe pumps. Improper loading or priming of the syringe can cause startup delays or prevent drug delivery. Failing to correctly secure the syringe can result in the piston moving the entire syringe rather than pushing the plunger into the barrel of the syringe. Loose tubing connections can result in a leak with loss of drug delivery to the patient. Improper priming occurs when the mechanical system is not fully engaged when the infusion is started. These delays are most significant with larger syringe sizes and lower flow rates. This can be especially critical with the very low rates (<10 mL/hr) often used in pediatric patients. At higher rates, startup delays are less of a concern. Several factors contribute to startup delays. They may result from mechanical gaps between the mounted syringe and the pump, and engagement of the gearing within the pump. Internal compliance of the syringe pump assembly and, to a lesser extent, compliance of the syringe and tubing also play a role. Using low-compliance syringes and tubing materials will reduce these effects. Air bubbles and antisiphon valves or other resistance elements in the line can also cause startup delays. Use the pump's purge function to prime the pump but do not purge into the patient's IV. Manually advancing the plunger will not completely prime the system because some slack may remain in the screw–piston connection.

Even when properly primed and programmed, there is a potential for flow errors. Bolus errors may occur after a line occlusion has been cleared, from pressure that has built up proximal to the occlusion. Simultaneously using syringe pumps and gravity infusions through the same line may produce unexpected flow dynamics. Fluid reflux with transient flow reversal and subsequent boluses can occur depending on variations in the flow associated with the gravity infusions. Irregular flow may also occur from faulty in-line components. Utilizing pumps with low mechanical compliance and rigid infusion lines for all fluids will reduce system compliance and improve the accuracy and consistency of infusion. Using smaller syringes can reduce occlusion alarm times and minimize waste. Other causes of syringe pump failure include erroneous programming; failing to turn on the device; clamping the tubing; and depleting the battery

instead of using AC power.

## Common Principles and Current Considerations

Infusion and syringe pumps must be set up and operated properly. Fluid connections must be made appropriately and aseptically. Drugs and their concentrations must be checked carefully to ensure that they correspond to the values entered and displayed on the pump. Careful inspection of the fluid path, including all connections, can help detect flow obstruction and inadvertent delivery failure due to leaks or infiltration. Often the first sign of an improperly functioning pump is the untoward effect of the incorrect dosage reaching the patient. Vigilance of the patient's condition is a must when setting up the pump and troubleshooting abnormalities. Labeling tubing at both the pump as well as the site of insertion into a common carrier can reduce subsequent problems. The carrier should be placed on a pump when administering medications that should not have unexpected fluctuations. Lines with drugs should be placed close to the distal end of the carrier tubing. This limits the dead space between the infusion line and the blood vessel and reduces delays between initiating an infusion and entry of the infusate into the patient.

Manufacturers have developed "smart" pumps that incorporate a variety of safety features that appear to make drug delivery safer. Perhaps the most significant of these features are the drug libraries which list the medications to be used with these pumps. These libraries can be programmed with a large variety of drugs that can be made specific to different institutions, clinical areas (e.g., OR vs. ICU), or contexts (pediatric vs. adult patients). These libraries promote the use of standardized concentrations and dosing protocols. Drug libraries typically include the drug name, diluent, concentration, units of measurement, and dosing protocols. These libraries also include lower and upper limits on dose or infusion rates. The pumps can have soft limits, which provide an alert when a dose or rate is above or below the desired range and require the user to determine if the pump was programmed correctly. The user can then decide whether to override the alert or reprogram the pump. Hard limits are dosing parameters that cannot be overridden and require either reprogramming or cancelling the infusion altogether in order to proceed. Hard limits can be very frustrating and lead to either delays or abandoning use of the library. Unfortunately, the user could also choose to use a workaround by selecting a basic infusion mode that does not incorporate the above safety features. ECRI Institute, a patient-safety organization formerly known as the Emergency Care Research Institute, rates pumps without these safety features as unacceptable.

"Smart" pumps can have the same problems found on traditional infusion pumps. These devices are still dependent on the user selecting the correct buttons on the keypad

while programing the pump. The user may accidently hit the same key twice or select the zero key instead of the decimal point key which is next to it on the pad. Not all errors will be prevented by a "smart" pump, especially if the erroneous entry is within the dosing limits of the pump. Vigilance is still essential and a significant amount of cognitive work may still be required to program a pump correctly. After initiating a change in dose or rate, it is essential to validate that the programmed change matches the intended results. Unfortunately, some displays may be hard to read from a distance or in poor lighting. This can be due to poor interface design, small screen size, poor screen contrast, and small font size or style. Pumps can automatically stop after a set volume is delivered or air is detected in the delivery path. Proper deairing of the line is critical to avoid pump failure and unintentional venous air embolus. Inadvertent delivery of a bolus can be avoided by disconnecting the tubing from the patient when clearing air or decompressing an obstruction. Multiple infusions can pose special problems. Reasonable drug compatibility must be ensured if using a common carrier line with multiple drugs. Spaghetti tangles of these infusions can cause obstructions, disconnections, and administration errors. Neatness counts.

"Smart" pump technology can result in new error modalities, such as those related to the use of complex drug libraries with large numbers of selections. These pumps are complex devices and not always easy to operate, and some users may choose to bypass the library altogether. There can be errors in the library entries, including drugs that are not entered in the library, as well as the potential to make a wrong selection from the library. Programming "smart" pumps involves a menu hierarchy that can be difficult to navigate. The work environment may predispose to shortcuts and workarounds, resulting in errors. Errors may be cleared without correcting them. Alerts may be ignored due to workload, they may not make sense, or they may be disregarded due to alert fatigue. In addition, drug libraries often include "wildcard" settings to allow administration of drugs not currently within the library. Dosing limits are not generally available in these situations; thus, the pump's ability to improve the safety of medication delivery is limited. Some errors cannot be detected by the "smart" pump. For example, if the wrong bag is hung, the device will not know. However, barcode medication administration and good labeling practices can reduce errors in drug identification. "Smart" pumps can communicate in real time with central servers and integrate with computerized physician order entry and the electronic medical record. The technology used in "smart" pumps allows the pump to store data on pump usage, infusion practices, and error logs. However, the compiled information is not usually available to the user in real time, and unless timely feedback is provided, it is likely the errors will occur again.

Pump alarms alert the user that there is a problem requiring the user's attention.

However, alarms often generate the same sound regardless of the alarm condition, and so may not specify or pinpoint the cause of the problem. The criticality of the alarm is often unclear, and it is not uncommon for alarms to be turned off, have limits set that preclude an alarm, or ignored altogether. Alarms can be a significant source of distraction. Alarms limits that are set too tightly will alarm frequently, often without clinical relevance. Limits that are too loose will not alarm and can delay recognition of a problem. An obstruction-to-flow alarm is probably the most useful type of alarm. The time for an obstruction-to-flow alarm to sound will depend on system compliance. This is often longer for syringe pumps than for other types of infusion pumps. If an obstruction-to-flow is allowed to last, not only will there be an interruption of drug delivery, but upon clearing the obstruction, it is also likely that a bolus will be delivered.

## TAKE HOME POINTS

- Be properly trained on infusion pumps before you use them on patients.
- Generally, peristaltic pumps are more versatile, but syringe pumps can be simpler to use in some situations.
- Carefully load, program, and label each drug and fluid.
- When initiating the administration of a drug, ensure that the device is properly connected and that flow is not obstructed.
- Use a carrier that is also on a pump.
- Use standardized concentrations, whenever possible, to avoid errors when programming the pump and changing bags or syringes.
- "Smart" pumps can reduce the likelihood of a medication error; however, vigilance is still necessary to ensure errors are not made.

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# Don’t Bring the Fiberoptic Scope Into the MRI Scanner!

Andrew Young, MD and Brian Mitchell, MD

Over the last few decades, Magnetic Resonance Imaging (MRI) has been increasingly utilized for complex imaging and many patients require sedation due to the length of time in the scanner and patient comfort. The complexity of sedation has increased due to medically challenging patients, underscoring the importance of qualified anesthesiologists providing safe sedation. We will review key elements of safe patient care in the MRI scanner, discuss key differences with the operating room (OR) environment, and offer pearls for providing anesthesia in this setting.

There are multiple hazards to patient safety with metallic objects becoming life-threatening projectiles inside the MRI suite. In addition, the practice environment and equipment used differ significantly from the traditional (OR) environment and this can add stress for and risk to the provider. Furthermore, with the increasing demand for sedation outside the OR, anesthesiologists are more likely to encounter emergency scenarios in the MRI scanner and be consulted for patient safety issues.

**The MRI magnet is thousands of times more intense than the earth’s magnetic field, and it is critical to remember that the magnet is always “on.”** MRI magnet strength is measured in Tesla units, with one Tesla equaling 10,000 Gauss. The earth’s magnetic field is approximately 0.5 Gauss, while typical refrigerator magnets are 10 Gauss. Clinical MRI scanners range in strength from 1 to 5 Teslas. MRI machines work by generating a strong magnetic field that surrounds the patient and excites hydrogen ions, which emit a unique energy frequency that is then measured by the scanner. The machine detects tissue contrast by the varying rates at which hydrogen atoms return to their equilibrium state.

**MRI machines can be louder than 85 dB.** Patients’ and providers’ hearing should be protected when near the MRI. The loud environment can make communication with patients and other providers difficult during scans. The loud environment can also make it difficult to hear alarms on the anesthesia and monitoring equipment; thus additional vigilance is necessary.

## Metals and MRI

As far as the MRI machine is concerned, only two types of metal exist: ferromagnetic and nonferromagnetic. Ferromagnetic metals include iron, cobalt, and nickel, which when exposed to a magnetic field become magnetic. Nonferromagnetic metals include aluminum, titanium, brass, and copper. Stainless steel is an example of a metal that could be ferromagnetic or nonferromagnetic depending on the particular mix of metals used in the alloy. Regardless of the metal's classification it is nearly impossible to visually inspect and know if a metal is ferromagnetic or nonferromagnetic. When in doubt, a small magnet can be used to test metals to determine if they are safe for the MRI scanner. We recommend that all metals be treated as ferromagnetic until proven otherwise.

Only MRI compatible equipment may be brought into the MRI room. Typically this equipment is clearly labeled in a conspicuous place on the equipment. Once inside the MRI suite, the magnetic field is on and the intensity increases exponentially with each step toward the magnet. Any ferromagnetic object may suddenly become magnetized and be attracted to the MRI scanner, becoming a projectile attempting to align with the magnetic field. Turn to the Internet for several enlightening examples. Sadly, patients have died when ferromagnetic objects, including oxygen tanks, have been pulled into the MRI scanner.

Given the significant potential danger to patients and staff, it is critical that the anesthesiologist work with MRI technicians to verify that the patient does not have any ferromagnetic implants in his or her body, including shrapnel and implants. Remember, metallic objects such as phones and pagers also pose a danger to providers and patients. Many MRI suites include X-ray devices to quickly verify that no metallic objects are within the patient. Of particular importance is verifying that no metallic objects surround vital structures such as the heart (pace makers, valves, stents), eyes (shrapnel), or brain (aneurysm clips, deep brain stimulators). In an emergency scenario operators can quench the magnet, which may completely or partially shut down the magnetic field. You should know how this is done before bringing a patient into the MRI scanner.

## Anesthesia Equipment

Anesthesia machines must be modified to safely operate within a magnetic field. These modifications include reducing ferromagnetic components to less than 2% of the machine's total weight. The anesthesiologist should anticipate these changes and be familiar with the machine before using it for patient care.

In addition to anesthesia machine modifications, all other anesthesia equipment used must be safe for use in the MRI suite. Drug infusion pumps must be specially modified as well, and may have a different interface than those normally used in the OR. Again,

the anesthesiologist must be familiar with these differences. Standard American Society of Anesthesiologists (ASA) monitors must be used during an anesthetic although the devices may be different than those found in the OR. For example, telemetry leads cannot be coiled on top of the patient but rather are positioned such that the leads are straight to avoid any interference with the magnetic field. Some MRI suites include wireless telemetry leads that can be plagued by signal interruptions and may be inconsistent with the patient's baseline EKG. In addition, these monitors may display information in an unfamiliar format, potentially delaying recognition of important changes in vital signs. We recommend that anesthesiologists familiarize themselves with these monitors and their displays before using them.

## Airway and Emergency Management

We recommend that patients who will receive general anesthesia be induced outside the MRI suite where any necessary airway equipment could be freely and safely used. LMAs and specially designed MR compatible laryngoscopes can be used in MRI room but other more advanced airway equipment cannot. This is especially critical in patients with a known or suspected difficult. Airway equipment including traditional laryngoscopes, video laryngoscopes, and fiberoptic scopes are not safe to bring into the MRI suite. Should an airway emergency arise during an MRI scan and non-MR compatible equipment becomes necessary to secure the airway, quickly move the patient on the MRI-safe gurney outside the MRI suite.

Anesthesiologists should be aware that the airway is usually inaccessible during MRI scans—the scanner tube is small, narrow, and the machine is large. Managing the airway from the head of the bed is nearly physically impossible in this setting. This underscores the importance of appropriate patient selection and securing the airway when indicated before starting the scan. While the scan can be interrupted, the patient should be stabilized as much as possible before starting the imaging. In addition, the anesthesiologist should consider what vantage points are most advantageous for monitoring the patient—there may be several different locations providing different types of visual information.

In a cardiovascular arrest scenario, the patient must be quickly moved outside the scanner to use the defibrillator as these are typically not MRI-safe devices. You should be familiar with your hospital's emergency protocols for patients in the MRI scanner. We recommend locating the nearest code cart when setting up monitoring equipment before bringing the patient into the MRI scanner.

Carefully consider the patient's disposition after the MRI is complete. Depending on the level of sedation provided, patients may require a postanesthesia care unit (PACU) environment to recover from the anesthetic in a closely monitored setting. The PACU

may not be near the MRI scanner, and thus the patient may require vital sign monitoring during transport.

## TAKE HOME POINTS

- Avoid all ferromagnetic objects inside the MRI suite, including implants, shrapnel, or personal items. Remember to screen the patient, yourself, and all staff entering the room.
- Plan ahead for emergencies in the MRI scanner. Emergency equipment such as defibrillators and airway equipment may not be safe to bring into the MRI suite.
- Monitoring equipment may be different from equipment typically used to in the OR. Familiarize yourself with these before using them for clinical care.
- Know how to quench or shut down the magnetic field of the MRI in an emergency situation.
- Consult the ASA practice advisory for MRI safety for a more detailed review.

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# Understanding the Operating Room Circuit and the Line Isolation Monitor—It's Really Pretty Simple

Richard Botney, MD and Jeffrey D. Dillon, MD

Simply put, the line isolation monitor (LIM) is a device that can reduce the risk of macroshock by alerting us with audible and visual alarms when the isolated power supply in the operating room (OR) is converted to a grounded power supply.

The use of electricity in the OR is associated with several risks to patients and staff. Macroshock and ventricular fibrillation (VF) may occur in conjunction with currents in the 100 milliamperes (mA) range. In situations where the skin barrier is breached and there is a direct communication to the heart (e.g., by a central line, pulmonary artery catheter, or externalized pacemaker wires), microshock may cause VF at current levels in the 50 to 100 microampere (μA) range. The goal in preventing electrical shock is to ensure that the patient and staff do not become part of an electrical circuit. As shall be seen, using ungrounded power supplies is an important method for accomplishing that goal.

## Basic Electrical Terminology

In order to understand how this occurs, it is necessary to understand the difference between direct current (DC) and alternating current (AC) power, the difference between resistance and impedance, and the concept of capacitance.

DC refers to a constant voltage, with current that flows at a constant level. The term resistance (R) is used to describe the relationship between voltage (V) and current (I) and is defined by Ohm's Law, $V = IR$. One example of this is a battery, with voltage and current output that does not vary over time. AC refers to voltages and currents that vary with time. This is the type provided by the power company, and the variation is typically a sine wave at 60 Hertz (Hz, cycles per second). A capacitor is defined as two conductors separated by an insulator. While there are specific electrical components known as capacitors, in fact any two conductors separated by air (or any other insulator) will also have capacitance. For DC, a capacitor is an open circuit, and no

current can flow between the two conductors; it has essentially an infinite resistance. In contrast, AC can flow across a capacitor. Instead of resistance, the equivalent term "impedance" (Z) is used for AC circuits, but Ohm's Law still applies. The impedance presented by a capacitor is inversely proportional to the capacitance and the frequency. The larger the capacitance and/or frequency, the less impedance the capacitor presents.

## Grounded Power Systems

The first step in understanding how the LIM reduces the risk of electrical shock is to understand the difference between grounded and isolated (ungrounded) power supplies. Electrical power is supplied to homes and other buildings in the form of a grounded system (Fig. 110.1). One wire, known as the "hot" lead, carries electrical current to the user. A second wire, the "neutral" lead, returns current back to the power company, while a third wire, the "ground," is physically connected to the earth. For example, most homes literally have a metal pipe sunk into the earth that establishes the ground connection. In grounded systems, the neutral wire and the ground are physically tied together. As a result, electrical current that flows in the ground lead can return to the neutral wire and thus back to its source.

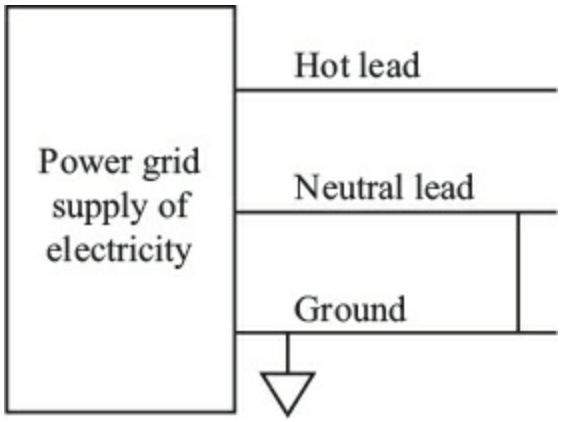


**Figure 110.1.** A schematic depiction of a grounded power supply, showing the hot wire delivering power from the power company, and the neutral and ground conductors physically connected. Anyone contacting the hot wire can thus have electrical current flow through that person to ground, and consequently to the neutral wire back to the power company.

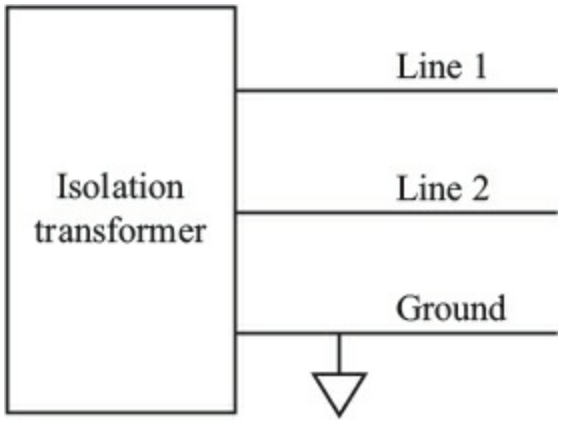


**Figure 110.2.** A schematic depiction of an ungrounded (isolated) power supply, showing the isolation transformer providing leads 1 and 2, which deliver power to electrical equipment, and a ground conductor that is not connected to either lead 1 or lead 2. During normal operation, anyone contacting either lead 1 or lead 2 cannot complete the circuit, as current cannot flow from ground to either of the other leads.

## Isolated Power Systems

In contrast, isolated power supplies, such as those found in the OR, have power supplied to equipment via two wires, known as "lead 1" and "lead 2." There is still a ground wire, but it is not connected to either lead 1 or lead 2, and so there is no pathway by which electrical current can get from ground back to the source (Fig. 110.2).

To better understand the significance of this, it is necessary to appreciate an important characteristic of electricity. Electricity must have a complete circuit to flow. In other words, an unbroken pathway must exist, and current must always flow back to its point of origin. This concept can be better understood by considering what would happen if there was a break in the pathway (an "open" circuit): current flowing would result in an accumulation of electrical charge at the break, and such charge would repel electrical charges and prevent further current from flowing. It is only when the circuit is complete that current will continue to flow. Consequently, electrical current must return back to its point of origin to complete the circuit.

As a result, anything that is conducting electricity and carrying an electrical current, including a human being, must therefore be in contact with a circuit at two locations. For example, if one could somehow float in the air, it would be possible to touch a hot wire and not experience a shock. However, when a human stands on or is in contact with the ground (in a grounded system), one of those connections has already been established. If a hot wire is contacted, the circuit is established and electricity will flow through the human to ground, then from the ground to the neutral wire, and back to its source. The human has become part of the circuit and a shock is received. This situation is described by saying that only one "fault" (connection to a circuit) needs to be established for a person to receive a shock. The second connection was present by virtue of the person's contact with ground.

A different circumstance exists for the isolated power system. Even though the individual is still standing on the ground, the ground no longer has a physical connection to either lead 1 or lead 2. Thus, a person standing on the ground can safely touch either lead 1 or lead 2 with no risk of current flowing through that individual. There is no possible pathway through the human back to the current's place of origin. It is only if the human comes in contact with both lead 1 and lead 2 that a current pathway is established. Hence, it is said that with an isolated power supply, two faults are necessary to allow an electrical shock to occur. That is, two points of contact must be made to get a shock. This represents an extra "layer" of safety and is one reason for using isolated power in the OR. Another way to look at this situation is to understand that ideally, a patient should never be connected to or in contact with ground—hence the adage "ground the equipment, not the patient." Because it is difficult to ensure that a patient is never in contact with ground, the OR itself is "disconnected" from ground by using an isolated (ungrounded) power supply.

## Conversion of an Isolated Power System to a Grounded System

There are essentially two mechanisms by which isolated power can convert to a grounded power supply. In the first case, a faulty piece of equipment is plugged in; the item in question has some sort of undesired connection between an internal wire carrying power (likely the neutral conductor) and ground. As a result, the system becomes grounded. Alternatively, if too many pieces of equipment are plugged in, the resultant accumulation of leakage (i.e., a reduction in impedance between either lead 1 and ground or lead 2 and ground) is sufficient to render the system grounded.

There are numerous sources of capacitance, and hence leakage, in the OR. Not only are there numerous pieces of electrical equipment present, the wires in each power cord also possess some capacitance between each current-carrying wire and the ground conductor. Consequently, the more equipment plugged in and utilized, the greater the total capacitance, the lower the impedance, and the greater the leakage. It is this leakage, due to capacitance between all these conductors, defined as "capacitive coupling," that can convert isolated power to a grounded power supply.

When an isolated power system is converted to grounded power, only one fault (contact with a live wire) is then needed to get a shock, and it is therefore less safe than when an isolated power supply is used (provides two "layers" of protection). Even though power is now grounded, the equipment in use continues to function and there isn't any indication that such a change has occurred. A LIM is used to detect and alert us when an isolated power supply has converted to a grounded system.

## Line Isolation Monitor

The LIM measures the impedance due to capacitive "coupling" and displays it as the current that could flow should there be a fault; for example, a person comes in contact with either lead 1 or lead 2. Older LIMs would alarm once the impedance dropped to a level equivalent to 2 mA leakage current. Since each piece of equipment could have as much as 100 μA leakage, and given the increase in the number of items of equipment, the older LIMs were alarming too frequently, and current models are now set to alarm at 5 mA. This does not appear to have degraded safety to any appreciable degree.

The final and arguably most important issue is how to respond to a LIM alarm. Knowing that the LIM may alarm because too many pieces of equipment have been plugged into wall power, or that some piece of equipment has a ground fault, defines the response to an alarm. Beginning with the item most recently plugged in, then the one before that, and so on, start unplugging pieces of equipment until the LIM no longer alarms.

There are several ways to tell if it is a faulty item versus too many items plugged in. Suppose an item is plugged in and the LIM alarms. When the item is unplugged, the alarm stops, which suggests it was that final piece of equipment. It is still unknown whether the item is faulty or not. If it has a ground fault, the magnitude of change on the meter associated with the LIM will be significant, whereas if it is simply one too many items, the magnitude of current change will be much smaller, on the order of 100 μA. Alternatively, you can take the offending piece of equipment to another OR (preferably one not in use) and plug it in there. If faulty, it should alarm in that location, too. In that case, it should be removed from service and sent for repair.

It is important to understand that a LIM cannot protect against all electrical events. For example, microshock occurs at current levels far below the alarm limits of LIMs. It also does not protect against mishaps resulting from use of electrosurgical equipment (the Bovie), particularly those involving the dispersive electrode. This gel-coated pad is often erroneously referred to as the "grounding pad." It **does not** ground the patient; instead it provides a large area, low-resistance pathway for the return of current from the handheld electrosurgical electrode (the Bovie "pencil"). In doing so, it prevents high-frequency electrosurgical currents from seeking alternate pathways to leave the body and return to the electrosurgical generator, such as via electrocardiogram electrodes or contact points between the patient and the OR table, thereby minimizing the risk of burns associated with electrosurgical equipment.

### TAKE HOME POINTS

- Voltage, current, and resistance (or impedance) are related by Ohm's law.

- The magnitude of macroshock current required to induce VF is on the order of 100 mA.
- To minimize the risk of shock, the patient should not be in contact with the ground. To ensure this, the entire OR is isolated from ground by using isolated power supplies.
- Activation of the LIM alarm does not mean an electrical shock has occurred; rather, it means that the isolated power system in the OR has converted to a grounded system in some way and that a second fault could harm a person.
- Upon such activation, unplug pieces of equipment sequentially, starting with the last piece of equipment that was plugged in before activation of the alarm. If it has a ground fault, do not use it until it can be repaired.
- The LIM cannot protect against microshock.
- The dispersive electrode of an electrosurgical unit is erroneously called the grounding pad. It does not ground the patient. Instead, it provides a low-resistance pathway for current to return to the electrosurgical unit, reducing the risk of burns.

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# Cell Phones in the Operating Room—Here Are the Issues

R. Scott Herd, MD and Juraj Sprung, MD PhD

The modern healthcare environment continues to evolve with the application of increasingly sophisticated electronic medical equipment and communication technologies. Similarly, smartphones, tablets, and other wireless devices are ubiquitous in the United States and around the world. Not surprisingly, mobile phones have gained increased presence in hospital settings as a means of communication between colleagues and for accessing medical decision-making tools. Some reports suggest that mobile phones may improve patient care through early notification of lab results and images. Others report a reduction in medical error or injury resulting from communication delays when compared to pagers. However, anesthesia providers must consider potential dangers to patient safety that mobile phone use may present in an operating room environment. Possible risks are related to cross contamination and infection through bacterial colonization of mobile phones, excessive noise and distraction, compromise of confidentiality (i.e., the use of cell phone cameras in the hospital, or public discussion of confidential issues), and even fire safety when mobile phones are charged near an oxygen supply. However, the primary danger relates to electromagnetic interference (EMI) with medical devices, which is the focus of the present chapter.

## Mechanisms of Electromagnetic Interference

Radio waves can induce currents within electrical circuits. Some electrical circuits are designed for this purpose (e.g., an antenna), which is the basis for the use of radio waves as communication signals. Unfortunately, radio waves can sometimes induce unwanted electrical currents within the circuitry of medical devices, thereby causing interference. This phenomenon is known as EMI. Cellular telephones operate on radio frequencies that are reserved for their use, so even medical devices that are designed to receive data via radio waves are unlikely to mistake a cell phone transmission for an appropriate incoming signal. Rather, cell phone radio waves can create interference by

inducing currents within circuits that were not designed to receive radio waves at all.

Three factors determine whether a wireless device will cause EMI with medical equipment: proximity, power, and shielding. Risk decreases with distance and increases with higher transmission power. A cell phone's transmission power varies inversely with the strength of the signal it receives from its cellular tower. A cell phone receiving a strong signal will decrease its output to conserve battery life; a phone receiving a weak signal will increase its output to ensure more reliable reception. This is particularly relevant in some hospital areas (e.g., operating room) which are in the basement or located away from outside walls. Importantly, power output is always at a maximum when the cell phone is ringing and remains high until the call is answered, declined, or transferred to voice mail.

Characteristics of the medical device can decrease vulnerability to EMI. Nearly all modern manufacturers shield devices, using conductive outer casing, according to suggested international standards. Other devices, such as telemetry equipment which must receive electrical or radio signals, instead rely on filtering mechanisms to prevent interference by cellular and other stray frequencies.

## Effects of Electromagnetic Interference on Medical Devices

Numerous reports have documented cell phone use interfering with the operation of medical devices. This has prompted most health care institutions in the United States and Europe to enact restrictions on cell phone use within certain patient care areas. The devices most commonly affected by EMI are electrocardiographic (ECG) and other intensive care monitors, which may cause increased signal noise, baseline movement, or even system crash. One study also demonstrated EMI with automated external defibrillators (AED), showing distorted monitor display and voice commands in response to nearby cell phone use. However, at no time did an AED fail to deliver or incorrectly deliver a defibrillator shock because of EMI.

Mechanical ventilators, drug infusion pumps, ultrasonographic probes, anesthesia machines, dialysis machines, and heart–lung bypass machines have all shown vulnerability to EMI. In regard to mechanical ventilators, effects include change of readouts, variation of operation (including changes in rate, tidal volume, and positive end-expiratory pressure), inappropriate triggering of alarms, and shutdown. EMI from a cell phone has been implicated in the death of a patient because of ventilator shutdown. Another fatality was related to acute epinephrine toxicity caused by mobile phone use in the vicinity of a syringe pump in which the therapeutic set rate was reprogrammed to 999 mL/hour.

Implantable cardiac devices seem relatively immune to EMI. Permanent pacemakers

have demonstrated overpacing and underpacing but never at a distance greater than 2 cm between the cell phone and the pacemaker pocket. Also, newer pacemakers that include electromagnetic filters have not shown any vulnerability. Likewise, implantable cardioverter-defibrillators also have shown no vulnerability to EMI resulting from nearby cell phone use. However, one report documented an incident in which an antitheft scanner in a bookstore caused the device to deliver inappropriate shocks.

## Risk of Electromagnetic Interference

Despite the evidence of EMI with medical devices resulting from nearby cell phone use, clinically relevant risk is difficult to quantify. Studies have reported the incidence of EMI ranging from 4% to 60%, but often without rigorous standardization of testing protocols or of devices tested. Older medical devices coupled with analog-type cellular telephones increased the likelihood of EMI. Analog cellular service has been discontinued among all major mobile phone carriers in favor of digital signals that offer enhanced features such as text messaging and data services. However, it is unclear whether these higher-frequency signals decrease the risk of EMI. Updated medical equipment also benefits from improved radiofrequency shielding and filtering technology.

Proponents of cellular phone use in patient care settings argue that much of the reported effects of EMI (such as ECG signal noise and inappropriate sounding of ventilator alarms) are a nuisance but do not ultimately alter patient care. When defined as EMI that hinders data interpretation or alters patient treatment, clinically relevant interference has been shown in 4% or fewer of devices. One review found this proportion to be less than 1% when the distance between the phone and the device is 1 m (3 feet) or more. Another report on the use of cell phones in the hospital environment reported no clinically important interference in 300 tests performed. Cell phones were used in a “typical manner,” but the authors did not specify proximity of the cell phone to the medical device tested. Finally, this report is from a single institution (Mayo Clinic) with relatively new medical equipment that may be less prone to interference.

## Regulation and Standardization

At present, the U.S. Food and Drug Administration uses EMI vulnerability standards set by the International Electrotechnical Commission when it evaluates medical devices for approval. Devices compliant with these standards should be vulnerable to EMI only at distances of 50 cm or less. This practice has been in place since 1998 and helps explain why newer devices seem to be more resistant to EMI. However, a device is not legally required to meet these or any other standards to attain approval.

Guidelines regarding the use of cellular telephones in hospital settings have been

issued by the Emergency Care Research Institute (ECRI), a prominent private hospital advisory group. ERCI's most recent report from 2006 recommends that health care facilities individualize their policies in order to balance interference risks with potential benefits. Cell phone use by patients and visitors remains discouraged in highly instrumented areas such as critical care units and emergency rooms. While hospitals may consider allowing wider use of cell phones by clinical staff, a distance of at least 1 m—and preferably more—must be maintained from medical equipment when using a cell phone. This ECRI report also presents several alternative technologies for convenient communications between providers.

## TAKE HOME POINTS

- EMI with medical devices resulting from nearby cell phone use is a documented problem and has harmed patients.
- The risk of EMI increases as the distance between the cell phone and the device decreases; a minimum distance of 1 m from medical equipment is recommended.
- Likewise, the risk of EMI resulting from nearby cell phone use increases as the phone's power output increases; a phone's power output is always greatest when it is ringing and remains at full power level until call is answered.
- To provide the safest possible care, anesthesia providers should be aware of EMI, especially with older medical devices, resulting from nearby cell phone use and should consider it as a possible cause in cases of equipment malfunction.

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# Don’t Let the Tourniquet Cause Extra Pain or Complications

Byron Fergerson, MD, Randal O. Dull, MD PhD, and Brian Mitchell, MD

A wise anesthesiologist once facetiously remarked that tourniquet use requires its own little anesthetic plan—discussion of risks and benefits, inflation (equals induction?), maintenance, deflation (equals emergence?), and posttourniquet (equals postoperative?) pain management. There is a kernel of truth in this.

Tourniquets are often used during surgery on extremities to decrease overall blood loss and to facilitate operating conditions by keeping the surgical field clear of blood. To deliver effective patient care, anesthesia providers must maintain a state of vigilance over all aspects of tourniquet use. Surgeons must explain the risks and benefits of a tourniquet and consent patients for their use. Tourniquet use may also necessitate a separate discussion between the anesthesia provider and the patient, especially if a regional block is planned to reduce associated pain.

Application of the tourniquet is often preceded by exsanguination of the limb using circumferential wrapping of the limb in an Esmarch bandage. An alternative to an Esmarch bandage is elevating the limb for 5 minutes (at 90-degree and 45-degree angles for upper and lower extremities, respectively). The cuff should be approximately 7 to 15 cm greater than the circumference of the limb and should be placed at the site of maximal circumference. Padding should be placed under the cuff with no obvious folds.

Protocols for tourniquet use vary among individual institutions and published guidelines differ among organizations. For example, the Association of Surgical Technologists recommends a cuff pressure of 50 mmHg above systolic blood pressure for upper-extremity procedures and a cuff pressure of 100 mmHg above systolic blood pressure for lower-extremity procedures. They also recommend an inflation interval of 60 minutes for upper-extremity procedures and 90 minutes for lower-extremity procedures followed by a 15-minute reperfusion interval. Wakai et al. suggest using a cuff pressure of 50 to 75 mmHg above limb occlusion pressure with a 30-minute reperfusion interval after 2 hours of cuff inflation. Individual institution protocols should be followed, or a tourniquet plan should be discussed and agreed upon between

the surgical and anesthetic teams prior to the procedure.

There is a considerable body of literature on the consequences of tourniquet application. While the physiologic changes associated with tourniquet use are well established, long-term functional limitations are rare. Animal models have shown that cuff inflation intervals <2 hours are safe, although the threshold for cuff pressure is less clear. Cuff pressures <300 mmHg do not appear to be associated with long-term problems.

## Muscle

Predictably, tourniquet use affects muscle tissue. During tourniquet inflation, the combination of acute ischemia and pressure may cause increased microvascular permeability. Cellular hypoxia occurs within minutes of inflation. **Ischemic cells release lactic acid, lysozymes, myoglobin, proteolytic enzymes, and inflammatory mediators, including histamine, leukotrienes, platelet-activating factors, and oxygen radicals.** All of these substances are redistributed into the systemic circulation immediately after tourniquet deflation and may cause significant vasodilatation and hypotension. In addition, venous stasis distal to tourniquets allows the accumulation of high levels of $CO_2$ and metabolic byproducts, including potassium, which may cause arrhythmias. After tourniquet deflation, reperfusion hyperemia can lead to compartment syndrome, rhabdomyolysis, and the post-tourniquet syndrome of stiffness, pallor, and weakness.

## Nerves

Nerve conduction stops approximately 30 minutes after inflation of the tourniquet, possibly due to axonal hypoxia. Nerve injuries, from simple paresthesia to paralysis, have been reported following tourniquet use. Nerves are most commonly injured at the edges of the tourniquet where the applied pressure is greatest. **The radial nerve is the nerve most commonly injured by tourniquets, followed by the ulnar and median nerves.** The overall incidence of tourniquet-induced nerve injury in the upper extremity is 1 in 11,000 procedures. In the lower extremity, the sciatic nerve is the most susceptible, with injuries occurring in approximately 1 in 250,000 procedures. The use of Esmarch bandages to exsanguinate the upper limb increases the risk of injury, because it can generate pressures of as much as 1,000 mmHg.

Tourniquet use can be painful and patients who are awake during tourniquet use may show signs of discomfort. The patient may deny incisional or operative pain but complain bitterly of an aching or burning pain in the distal extremity. Slow, unmyelinated, C-nerve fibers are thought to be responsible. Under normal circumstances, pain impulses from fast, myelinated A fibers inhibit C-fiber conduction,

but these fast fibers are more susceptible to compression and are thus blocked earlier, leaving C-fiber conduction uninhibited.

The anesthesia provider must manage pain from tourniquet use on an ongoing intraoperative basis. Because pain may be experienced as soon as 30 minutes after inflation, the patient may say that "the block is not working." Sedation may help, but, unfortunately, pain from tourniquet use does not respond to opioids or sedatives in a predictable manner.

A very dense sensory block with a long-acting local anesthetic may provide the best chance of avoiding pain from tourniquet use. For the upper extremity, an adjunctive "ring" or musculocutaneous nerve block may also be done with 10 mL of local anesthetic, often an equal-parts mixture of lidocaine and bupivacaine. Neuraxial or other regional nerve blocks can be used for lower-extremity tourniquets. Remember that, in the limb bearing the tourniquet, sensory levels must be assessed by touch instead of pinprick. Blockade of the nerve fibers associated with touch occurs more slowly and regresses more quickly than blockade of those associated with pinprick sensation. Local anesthetic adjuncts including epinephrine, morphine, and clonidine may be considered to increase the duration of the sensory block.

## Cardiovascular Considerations

Significant blood volume shifts can be associated with inflation and deflation of the cuff. Exsanguination of and inflation of the cuff on a lower limb can lead to a 15% increase in circulating blood volume, thus increasing the pulmonary artery, central venous, and systemic arterial pressures. These effects can be exaggerated in patients with severe varicose veins or poor left ventricular compliance. Patients under general anesthesia will show an increase in blood pressure and heart rate after cuff inflation due to increased circulating blood volume. Deepening the level of anesthesia does not always effectively resolve this problem, and use of vasoactive substances may be necessary. This should be done with caution because the hemodynamic effects of inflation are reversed at deflation and reperfusion. Anesthesia practitioners at all levels are usually prepared for an initial decrease in the hemodynamic state; what sometimes surprises less-experienced practitioners is how persistent it can be. If antihypertensive medications must be used when the tourniquet is up, use of short-acting medications is best.

## Hematologic Complications

Thrombosis is a potential complication of tourniquet use. However, study results regarding whether tourniquet use actually increases the incidence of deep-vein thrombosis and subsequent pulmonary embolism are inconclusive. **Several studies**

**using transesophageal echocardiography have documented emboli in the right atrium following cuff deflation in almost all patients having total-knee arthroplasty.** Emboli tend to form in a large portion of lower-extremity surgeries, regardless of whether a tourniquet is used, but tourniquets are associated with larger, more hemodynamically significant emboli. Sickle-cell disease is considered a relative contraindication to tourniquet use because the hypoxic and acidotic environment distal to the cuff may induce a vaso-occlusive crisis. However, several studies suggest that if normothermia, normocarbia, and normoxia are maintained and the limb is properly exsanguinated, tourniquets can be used safely in patients with sickle cell disease.

## Pharmacokinetics

Tourniquet inflation and deflation also alter drug kinetics. Drugs given before inflation may be sequestered in the limb, although this is of uncertain clinical significance. Antibiotics should be given at least 5 minutes before inflation to ensure adequate concentrations at the surgical site. Drugs with large volumes of distribution, such as fentanyl and midazolam, have prolonged durations of action when given after inflation, particularly in the elderly.

### TAKE HOME POINTS

- Tourniquet inflation intervals <2 hours are not associated with an increased risk for long-term morbidity.
- If the surgery is expected to be >2 hours, a reperfusion interval should be planned for ahead of time and agreed upon by the surgical and anesthetic teams.
- Tourniquet cuff pressures <300 mmHg are not associated with long-term morbidity.
- Tourniquet pain can be severe but may be ameliorated with a sensory block.

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## SECTION VII

# PERIOPERATIVE

# 113

# Introduction

Ryan J. Fink, MD

Any number of various challenges can crop up in the perioperative period. Therefore, in this section of the book, you will find a variety of topics discussed, without a single overarching theme—but that's what makes it so interesting!

Some of these perioperative challenges are commonly seen, but may also have nuances that are important to remember. For example, a large percentage of patients in the United States today have diagnosed obstructive sleep apnea (OSA), or are at high risk for it. This is a patient population that we see often coming to the operating room. And while the condition is common, we can't forget that these patients have a comorbidity that puts them at higher risk of perioperative complications. One of the more challenging questions related to OSA is, can this patient be safely discharged home after general anesthesia? Each hospital likely has a policy related to this question, and it is the practice at my institution to monitor OSA patients for 90 minutes after the last dose of IV opioids and discharge home if they have no episodes of obstruction or desaturation. We have also drawn on our own practices to provide information in dealing with tattoos and music in the operating room.

Other perioperative issues that we have included are ones that have had supporting evidence for many years, but sometimes still fly under the radar. Here I'm thinking of the chapters on perioperative smoking cessation, hand hygiene, avoiding residual neuromuscular blockade, and using CVP to guide fluid resuscitation. By now, these topics may be well known to most readers, but I think these new and revised chapters still provide a nice review for anyone who was thinking, "maybe, just maybe, I can protect those kidneys…."

Fortunately for patients, but unfortunately for providers wishing to maintain knowledge and remain skilled, many serious adverse events are now rare. In addition, some patient populations or comorbidities may not be seen often. Several of the chapters in this section may be useful as quick resources—for example, the chapters on schizophrenia (Chapter 123) and eye surgery (Chapter 145), and the new chapters on positioning patients (Chapters 127–133).

Hopefully this section will serve as both a refresher and a vehicle for new

information as it covers a range of perioperative/intraoperative topics to help keep us all on our toes.

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# Hurdles of the Electronic Health Record

Ishan A. Patel, MD and Jeffrey A. Gold, MD

Implementation of the Electronic Health Record (EHR) has been incentivized in the healthcare setting with the potential of improving the quality of healthcare, reducing overall cost, and promoting safety of patients. The power of the EHR lies in its ability to catalogue hundreds of patient-data points into one all-inclusive, accessible record available virtually anywhere. For us, specifically, one of the big benefits of having an electronic anesthesia record is the ability to easily go back and look at past anesthetics to look for airway and access issues, previous antibiotics, and so forth. With the growing number of physicians, nurses, and allied healthcare staff using EHRs across the world, there are many benefits of EHR that can aid healthcare workers in providing the best care to patients. Specifically, medical decision support implemented through the EHR is designed to prevent medical errors by alerting physicians and healthcare workers of potentially life-threatening events. These include examples such as potential medication errors, alerts to critical lab values, and identifying needed lab tests. However, the Institute of Medicine (IOM) report on Health IT and Safety, released in 2011, underscored the challenges associated with EHR implementation and taxonomically categorized medical errors associated with EHR implementation. Overall, the IOM report gave EHR safety a "C+," suggesting and highlighting the need for greater attention to these issues in order to prevent adverse health events. This chapter serves to address some of the potential negative, unintended consequences of the EHR in the acute care and operating room (OR) settings as well as underline some of the methods that can be employed as clinical providers to maintain EHR functionality for the benefit of the patient.

Perhaps the best lens to understand some of the negative aspects of EHR is by looking at Intensive Care Units (ICU). An average ICU patient generates over 1,400 data points/day during their ICU stay, with this value growing by 5% per year. For a given ICU census of 14 patients and an average ICU stay of 4 days, this implies that the average medical provider is responsible for over 75,000 data points/day. A healthcare worker providing care to these patients must be able to efficiently navigate and integrate these data points into trends in order to make a large number of clinical decisions in a

short timeframe. Currently, many commercial EHR systems lack the functionality to provide a coherent view of the patient's data. Furthermore, these systems are perceived as difficult to learn by the end-user and lack a well-organized user interface to expedite the presentation of complex data to facilitate clinical decision making. This is highlighted by the observation that <20% of providers feel their EHR is easy to learn and <40% are highly satisfied with their EHR system. As a result, medical providers are unable to assemble the collected data into decision-friendly interfaces which consequently can hinder the quality of care given to the patient. This is compounded by the observation that there are nearly 350 commercially available EHR systems in the United States, each with its own custom user interface, increasing the likelihood that a given healthcare provider will need to master multiple individual systems as part of their workflow. Therefore, EHR systems must be able to effectively and efficiently plot these data points in customizable systems for all types of healthcare workers, with this functionality, optimally, being universal across the spectrum of healthcare delivery systems.

As EHR systems become more and more integrated with monitoring systems to collect and record patient data, there is opportunity for automatic data capture into the patient's health record without the need for medical provider participation. In the case of anesthesia, the automated Anesthesia Information Management System (AIMS) electronically captures and preserves data from each case into an easily accessible health record thereby freeing up the medical provider. However, in the OR where the focus is the patient, having these automated EHR systems that are able to efficiently gather data points for each patient may actually be a hindrance to providing quality care. Examples include data capture failure (where the system no longer captures data or captures inaccurate data), manual entry requirements (where providers still have to provide information despite an automated system), or inappropriate timing of documentation, which can lead to providers switching back and forth from patient care and data entry. All of these mechanisms contribute to shifting the workflow of the medical provider that may lead to sources of error. Improper documentation during these events can be further used as a source of evidence in the event of litigation. Therefore, it is important to understand the functionality of the automated EHR system, its limitations, and develop efficient solutions in advance to problems that providers may face in the event of data capture failure.

The ability to simultaneously view hundreds of data points captured by the EHR, whether in anesthesia or critical care, can be helpful but can also introduce availability bias to the medical provider. The visualization of data at the appropriate time of decision making influences the ability of the healthcare provider to deliver precise care. The quality of the medical plan is directly related to the integrity, accuracy, and

reliability of the data presented. Clinicians can be influenced by the visualization of data sets to pursue pathologies that may not exist, or may be insignificant in the patient at the present. This becomes more complex as each member of the care team has a unique workflow with respect to the EHR. Thus, there exists the potential for significant interdisciplinary (e.g., different physician groups) and interprofessional (e.g., nurses vs. physicians) variability in data availability as well. Understanding how each EHR system displays data sets must be known by each provider on the healthcare team in order to limit availability bias and show only the data that is requested by the medical provider.

With the large amount of data available for display, whether requested by the medical provider or not, providers must be aware of the proportionate increase in the number of medical alerts associated with each patient. EHR systems, in an effort to promote patient safety, have built-in alert systems that flag potentially life-threatening or important findings in a patient for review by the medical provider. These alerts are based on population norms for healthy individuals and thus for healthy patients with normal histories and a paucity of clinical data, these alerts have a higher degree of specificity for clinically relevant abnormalities, improving their utility. However, in settings with a high prevalence of acute or chronically ill patients, such as the ICU or the OR, the concept of "alert fatigue" becomes readily apparent where patients are generating thousands of data points that can be all potentially flagged, day after day. This alert system, although useful in many situations, is not contextual and does not discriminate between chronic or acute findings in a patient; therefore, the medical provider is left with the task of dismissing flagged findings from chronic problems. Consequently, in "alert-heavy" patients, the medical provider could potentially miss acute alerts that are otherwise buried among those alerts from chronic issues causing errors due to data recognition. EHR systems, to adjust for alert fatigue, must be able to contextualize an individual patient's laboratory results and have alert systems that are customizable from the user's perspective in order to allow the provider to create an "alert setpoint" for a given patient to reduce alert fatigue. It is therefore left to the provider to customize their own set of actionable alerts based on the provider's specific medical environment.

A patient's health record not only contains objective laboratory reports but also written narratives documented by medical providers. With the widespread implementation of EHR, the medical record progress note has been a significant source of information about a patient for healthcare providers. Implemented by the EHR, the Subjective, Objective, Assessment, and Plan (SOAP) note remains a mainstay in conveying pertinent patient information with a consistent structure. While the structure of the SOAP note has remained unchanged, the content and quality of the note has

changed dramatically, considerably impacting communication between medical providers. Redundancy and over-completeness of the SOAP note (or any other type of progress note) impede effective and efficient communication about a patient. Often, providers "cut and paste" information from prior days within a consistent, fixed EHR template that can possibly contribute to inaccuracies leading to medical errors and litigation by failing to update information or overdocumenting medical care in support of billing more services. Similarly, the "draft" versions of the patient documentation—versions previous to the final version of the patient encounter documentation—can harbor sources of error with the potential of litigation using the prior edits as sources of valuable information in a prospective lawsuit. As medical providers, care must be taken in individualizing the charting and documentation for each patient to minimize these types of errors.

In summary, current EHR systems catalogue an information-rich patient record that has been maintained as an electronic version of the traditional paper chart. However, given the increase in the amount of data recorded for each patient, using an electronic version of the paper chart (i.e., current EHR systems on the market today) is ineffective in providing the best care to patients due to the many of the problems associated with EHR use. To overcome the hurdles of EHR in the current system, we must understand the limitations that existing EHR systems have placed on the healthcare system and develop novel methods to address some of the basic problems associated with EHR.

## TAKE HOME POINTS

- Data fragmentation/Data Overload: There are thousands of data points generated for an average ICU/OR patient. Use the trending functionality available in the EHR to plot this data in order to ease the decision-making process.
- Availability bias: Having easy access to multiple datasets to support your claim does not necessary prove your claim. Limit data analysis to only what was ordered to improve errors due to cognition.
- Alert fatigue: EHR systems do not analyze context of disease in patients and post alerts without regard to previous results. Be cognizant of alert fatigue and actively interface with the institution's health record information technology division to develop strategies in customizing alerts for the medical environment.
- Charting shortcuts: "cut and paste," "draft versions" can introduce widespread medical errors across patients and can be used in litigation. Document with a timestamp the things that are completed by you and use general templates/shortcuts instead of copying-and-pasting from different days or different patients. Another problem is that hospital electronic record networks have an ongoing tendency for slowdowns, freezeups, and so on. There is still the need to maintain the ability to do

paper charting when the case must go and the system is down.

- Effecting change: Interface with the institution's health information technology division to develop a reporting system for EHR problems that arise during patient care. Develop and use a standard form and protocol to effect change in EHR functionality per institution.

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# Hand Hygiene! History, Human Factors, and Helping Your Patients

Harriet W. Hopf, MD, James W. Ibinson, MD PhD, and David G. Metro, MD

You've heard it all your life: "Wash your hands!" Hand hygiene, which includes both washing hands with soap and water and cleaning hands with alcohol-based rinses, gels, and foams, is a primary component of infection control. **Yet physicians in general, and anesthesiologists in particular, are notable for their neglect of hand hygiene.** Studies by Noakes et al. and Pittet et al. demonstrated about a 40% rate of adherence to hand hygiene guidelines (range, 5% to 81%) and in 2009, Koff et al. found that compliance by anesthesiologists in the operating room is notably lower. A survey of anesthesiologists in the United Kingdom found only 36% reported washing their hands between cases (El Mikatti et al., 1999). In this chapter, we will consider the evidence for hand hygiene as an infection control measure, characteristics of hand hygiene products, barriers to hand hygiene performance, and approaches that encourage better practice.

The value of hand hygiene as a primary infection control measure was first demonstrated about the same time anesthesia was introduced. In 1847, the Hungarian obstetrician, Ignaz Semmelweis, wanted to understand why women who delivered their babies at a Vienna hospital staffed by medical students and physicians had a mortality rate of 5% to 15%, largely as a result of puerperal infections, while the rate at a nearby clinic staffed by midwife students and midwives was only 2%. The major difference in practice was that medical students and physicians usually started the day performing autopsies (including on patients who died of puerperal fever) and then moved directly to the labor ward to examine women in labor. Although germ theory was some years off, Semmelweis insisted that physicians and medical students wash their hands in a chlorinated solution between the pathology laboratory and the labor ward, which reduced the rate of puerperal fever to 2%. After this success, Semmelweis identified the possibility of transmission from an infected to an uninfected patient, and instituted the use of chlorinated solution handwashing between patients as well. He also demonstrated that the chlorinated solution was more effective than soap and water.

Unfortunately, his innovation was not widely adopted, resulting from a combination of slow publication of results, lack of understanding of why hand hygiene was effective (that is, germ theory), lack of tact in trying to convince healthcare workers to adopt his measures, and reluctance of colleagues to accept they might be vectors for transmitting disease.

Why is hand hygiene necessary, and how does it work? Bacteria on the skin cannot be completely eliminated (Boyce and Pittet, 2002). Resident flora are embedded in the deeper folds of the skin. These resident flora are more resistant to removal, but are not usually pathogenic. Transient flora, which colonize the superficial layers of the skin and are easier to remove, are more likely to be pathogenic and are the source of most healthcare–associated infections (HCAI). During patient care, the skin becomes contaminated from patient contact or contact with contaminated surfaces. Even noninvasive activities, such as applying monitors, increases transient flora such as Klebsiella species by 100 to 1,000 colony forming units (Casewell and Phillips, 1977). Contamination from surfaces is most commonly with organisms such as Staphylococci and Enterococci, which are resistant to drying. While no studies have related hand contamination to actual transmission of infection to patients, numerous studies, starting with those of Semmelweis, have demonstrated a reduction in HCAI following institution of hand hygiene or improved adherence to hand hygiene (Boyce and Pittet, 2002).

A number of products are available for hand hygiene. Plain (not antimicrobial) soap and water are generally the least effective at reducing hand contamination (Ehrenkranz and Alfonso, 1991). Although the detergent effect of soap and the mechanical action of washing has some effectiveness, bacterial load is not greatly reduced. Soap and water are, however, the most effective at removing visible contamination, viruses such as H1N1 Influenza, and spore-producing microbes such as Clostridium difficile or Bacillus anthracis (Boyce and Pittet 2004). Antibacterial soaps or scrubs containing triclosan, triclocarban, and chloroxylenol, iodine, or chlorhexidine, are more effective in the hospital setting. Soap and water hand hygiene is associated with high rates of skin irritation and drying, both of which are risk factors for an increased bacterial load.

Chlorhexidine is a germicidal cationic bisbiguanide that disrupts cytoplasmic membranes, resulting in precipitation of cellular contents (Boyce and Pittet, 2002). It is effective against gram-positive bacteria and lipophilic viruses, with somewhat less activity against gram-negative bacteria and fungi, and minimal against tubercle bacilli. It has substantial persistence on the skin. Recent reports have identified immunoglobulin E–mediated allergic reactions to chlorhexidine (Sivathasan and Goodfellow, 2011). It is present in a wide range of medical and community-based products, including wipes, impregnated central venous catheters, toothpaste, mouthwash, contact lens cleanser, and food preservatives, so potentially sensitizing exposures are common.

Iodine and iodophors (iodine with a polymer carrier) penetrate the cell wall and impair protein synthesis and cell membrane function (Boyce and Pittet, 2002). They are bactericidal against gram-positive, gram-negative, and some spore-forming bacteria including clostridia and Bacillus species, although inactive against spores. They also have activity against mycobacteria, viruses, and fungi. Their persistence is generally fairly poor. They cause more contact dermatitis than other commonly used agents, and allergies to this class of topical agent are common. Iodophors generally cause fewer side effects than iodine agents.

Alcohol-based rinses, gels, and foams denature proteins, and have germicidal antimicrobial activity (Boyce and Pittet, 2002). Antiseptics containing 60% to 95% ethanol in a water base are broadly effective against gram-positive and gram-negative bacteria; lipophilic viruses such as herpes simplex, human immunodeficiency, influenza, respiratory syncytial, and vaccinia viruses; and hepatitis B and C viruses. Combination with low doses of other agents such as chlorhexidine, quaternary ammonium compounds, or triclosan prolongs the effectiveness. Alcohol-based products are most effective when adequate volume (3 mL) is applied for a sufficient duration (30 seconds). Although use of alcohol-based products cause less skin irritation that washing with soap and water, repetitive use builds up residue on the hands that may be irritating, so periodic washing with soap and water is recommended.

While a number of guidelines for hand hygiene in the hospital environment have been developed and disseminated, adherence is distressingly low. Tait and Tuttle (1995) showed that when treating patients thought to be carrying HIV or HBV, 95% of healthcare workers washed their hands, while only 58% washed their hands after contact with the exact same patients when knowledge of HIV or HBV status was not known. This suggests healthcare workers understand the importance of hand hygiene in preventing the transmission of disease but fail to appreciate its importance in routine contact. One reason for the low rate of hand hygiene in anesthesiologists probably relates to now-outdated CDC guidelines for healthcare providers that focused on hand hygiene prior to entering and after leaving a patient room. An anesthesiologist following this recommendation would only perform hand hygiene less than once an hour, consistent with observational studies on anesthesiologist hand hygiene behaviors (Koff et al., 2009). More recently, the World Health Organization (WHO) developed a campaign highlighting the “Five Moments” of hand hygiene (Figure 115.1). The campaign emphasizes the need to perform hand hygiene before and after each contact with a patient or their immediate environment (Sax et al., 2007).

Given guidelines recommending hand hygiene before and after contact with the patient or their immediate environment, how often, on average, should anesthesiologists perform hand hygiene in the operating room? While this question has not been directly

studied, observational studies of hand hygiene opportunities for ICU nurses suggest about 20 times an hour during patient care (Boyce and Pittet, 2002). In the operating room, frequent patient contact by the anesthesiologist requires frequent hand hygiene, probably at about the level of nurses in the ICU. Inadequate hand hygiene increases the risk of contamination of the environment and cross-contamination of patients. Loftus et al. (2008) showed that bacterial contamination of the work area increased by about 100 colonies per surface area sampled during cases and that an increase in work area contamination to >100 colonies per surface area sampled increased the risk of intravenous stopcock contamination by almost five-fold. Stopcocks were contaminated with a variety of organisms, including methicillin-resistant Staphylococcus aureus (MRSA) and vancomycin-resistant Enterococcus.

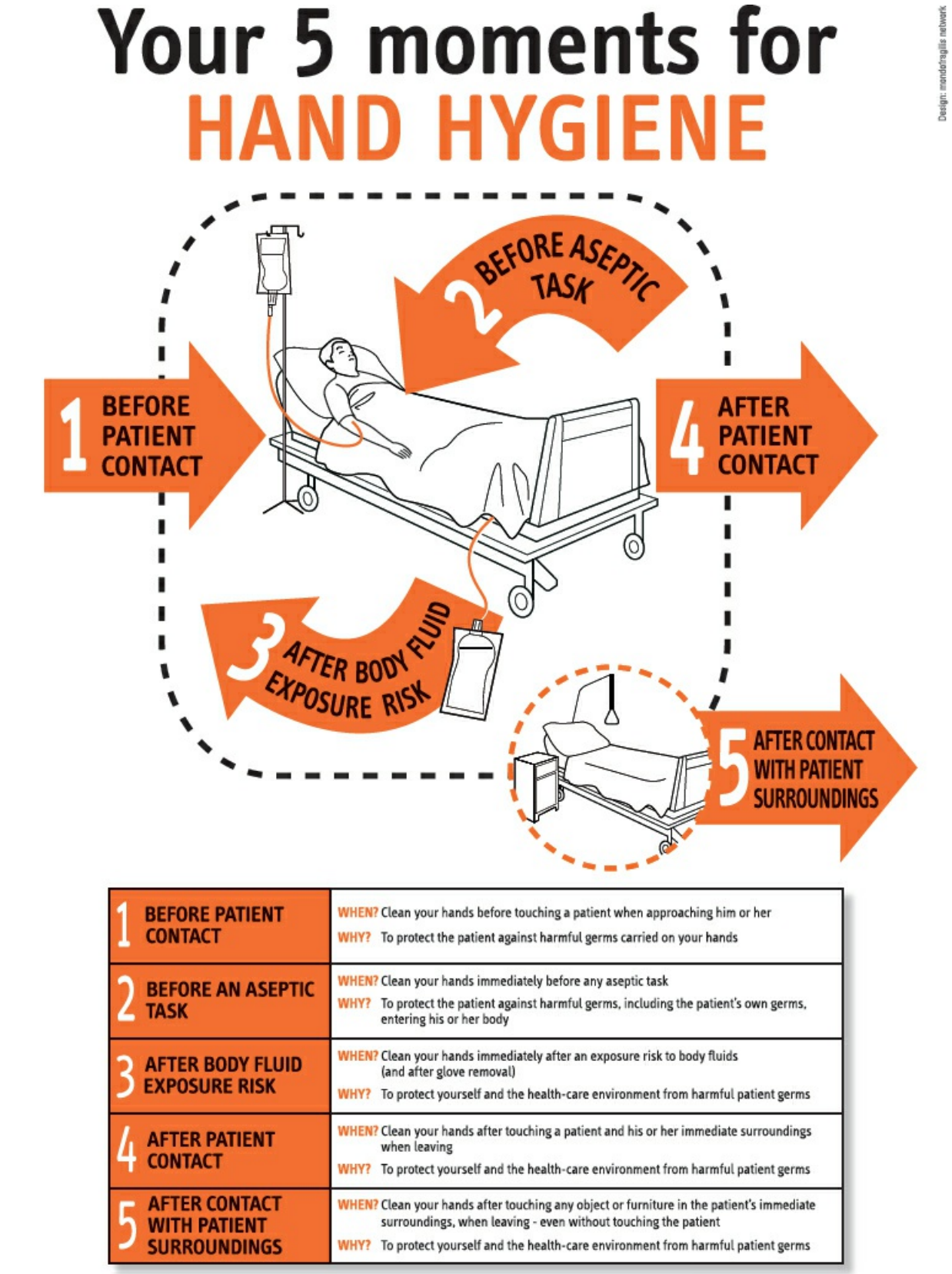


**Figure 115.1.** World Health Organization-Five moments of hand hygiene. (Reprinted with permission

from World Health Organization. My 5 moments for hand hygiene. Retrieved from https://www.who.int/infection-prevention/campaigns/clean-hands/5moments/en/).

Koff et al. (2009) performed a before-and-after study to evaluate education and use an alcohol-gel dispensing device that provided an audible reminder to perform hand hygiene 6 times an hour. Hand hygiene episodes increased from <0.5 per hour to 7 to 9 per hour. While hand hygiene opportunities were not measured and hand hygiene episodes were not necessarily coordinated with one of the Five Moments, the increased hand hygiene rate significantly decreased work area contamination, stopcock contamination (by 75%), and HCAIs. More recent studies by the same group demonstrate anesthesia provider's hands as a source of cross-contamination between patients (Loftus et al., 2015). Computer keyboards, telephones, and stethoscopes represent another concerning environmental source of cross-contamination (Fukada et al., 2008). Better hand hygiene practices reduce environmental contamination. Routine cleaning of equipment and surfaces by anesthesiologists with antimicrobial wipes also has a role in reducing the inevitable contamination that results from patient care, particularly after induction.

Transmission of bacterial contamination by the anesthesia provider is common, a potential source of nosocomial infections, and largely preventable. Frequent hand hygiene by anesthesia providers has a direct and positive impact on patient outcomes. How can we encourage anesthesiologists to take these data to heart and apply them in daily patient care? While education, monitoring, and feedback are important, a potentially high impact approach is reduction of barriers to hand hygiene.

Barriers to hand hygiene include skin irritation and fear of skin irritation, inaccessibility, time, lack of knowledge of best practices, and healthcare worker acceptance. Adherence to hand hygiene guidelines generally decreases as the frequency of indicated handwashing increases, as the workload increases, and as staffing decreases. Although alcohol-based agents have a reputation for causing more skin irritation, several recent trials demonstrated less skin irritation and better acceptance with emollient-containing alcohol-based hand rubs compared with antimicrobial or nonantimicrobial soaps. Skin irritation can be reduced by the use of glove-compatible lotion or skin protectant cream. In one study, the use of skin protection cream twice a day increased hand hygiene frequency by 50% (Boyce and Pittet, 2002). Providing skin protectants on the anesthesia cart may thus increase hand hygiene adherence. Alcohol-based gels and foams address accessibility, since dispensers may be pocket-sized or placed on the anesthesia cart and in other convenient sites. Alcohol-based products also require about 75% less time than going to a sink for handwashing. Soap and water must still be readily available, to remove particulate matter including blood and other body fluids, when caring for patients with C. difficile infections, and after five to ten

applications of alcohol-based agent. The open layout of most postanesthesia care units (PACUs) and many intensive care units (ICUs) also seems to lower hand hygiene compliance. Pittet et al. (2003) found that only 19.6% of healthcare workers cleaned their hands properly when admitting a new patient to the PACU.

Some healthcare workers treat gloves as a substitute for hand hygiene. Unfortunately, wearing gloves does not reduce the need for hand hygiene. Gloves become contaminated by patient contact, just as hands do. Gloves should be removed or changed immediately after each procedure, including vascular access, intubation, and neuraxial anesthesia, or patient contact. Although gloves provide personal protection, they do not prevent bacterial transmission to healthcare worker hands during patient contact (Boyce and Pittet, 2002). Therefore, hand hygiene should be practiced immediately after glove removal as well. Balancing hand hygiene with close attention to the patient during critical portions of the case (e.g., securing the airway) can be challenging. Double gloving and providing a convenient location for contaminated equipment have been suggested as effective approaches (Mecham and Hopf, 2011; Birnbach et al., 2015).

Although not a replacement for hand hygiene, gloves are an important component of both infection control and personal blood and body fluid precautions. Loss of touch has been cited by anesthesiologists as a barrier to glove use. Tiefenthaler et al. (2006) showed that touch sensitivity as tested by filament force on the fingertip required for sensation is reduced with either standard single-use protective gloves or sterile surgical gloves, while two-point discrimination was not significantly different. Kopka et al. (2005) examined single-use protective gloves, standard sterile surgical gloves, and extra-thin surgical gloves in terms of skin-pressure sensation. They found no significant difference between standard protective and surgical gloves but did note an improvement when using extra-thin surgical gloves. Although these studies may support the case against glove use in terms of sensation, arguments for routine use are strengthened by the finding that approximately 10% of all patients undergoing surgery can be infected with infectious viruses or MRSA, and that glove use can protect against up to 98% of blood-borne pathogens. CDC and ASA recommendations on this are clear, and the Occupational Safety and Health Administration (OSHA) requires gloves as part of its standard precautions.

**Table 115.1 ■ CDC Recommendations for Activities That Require Handwashing**

1) Decontaminate hands before having direct contact with patients.
2) Decontaminate hands before donning sterile gloves when inserting a

central intravascular catheter.
3) Decontaminate hands before inserting indwelling urinary catheters, peripheral vascular catheters, or other invasive devices that do not require a surgical procedure.
4) Decontaminate hands after contact with a patient's intact skin (e.g., when taking a pulse or blood pressure, or lifting a patient).
5) Decontaminate hands after contact with body fluids or excretions, mucous membranes, nonintact skin, and wound dressings even if hands are not visibly soiled.
6) Decontaminate hands if moving from a contaminated-body site to a clean-body site during patient care.
7) Decontaminate hands after contact with inanimate objects (including medical equipment) in the immediate vicinity of the patient.
8) Decontaminate hands after removing gloves.
9) Before eating and after using a restroom, wash hands with a nonantimicrobial soap and water or with an antimicrobial soap and water.

## Summary

Anesthesiologists hold the power to reduce HCAIs in their hands. Institutions should make alcohol-based hand hygiene and soap and water hand hygiene options easily and quickly available throughout the perioperative environment. Anesthesiologists should follow the Five Moments of hand hygiene while caring for their patients (Figure 115.1). Table 115.1 summarizes CDC recommendations for hand hygiene. Table 115.2 summarizes the American Society of Anesthesiologists guidelines for hand hygiene.

**Table 115.2 ■ Summary of Recommendations of the ASA for Hand Hygiene**

1) Handwashing with soap when visible contamination with blood or body fluids
2) Alcohol-based hand rubs when there is no visible contamination
3) Wearing of artificial nails is discouraged in operating rooms
4) Nail polish may be worn if not chipping or peeling
5) Rings should be removed prior to surgical hand scrub
6) Indications for hand hygiene include:

- Before and after contact with patients
- Before donning sterile gloves
- After contact with body fluids, nonintact skin, mucous membranes, wound dressings
- When hands have contacted a contaminated body area and will subsequently contact a clean site
- After contact with high-touch environmental surfaces in the vicinity of the patient
- After removal of gloves
- Before eating
- After using the restroom

7) Gloves should be worn whenever contact with blood, body fluids, mucous membranes, nonintact skin, or other potentially infectious material is anticipated
8) Gloves should not be reused

## TAKE HOME POINTS

- The CDC, WHO, and ASA recommend that hands be cleaned before and after all contact with patients or their environment and potentially when touching two areas of the same patient.
- Alcohol-based hand scrubs, soap and water, and gloves all have a place in hand hygiene in the perioperative environment. Convenience, access, comfort, and potential pathogens determine the choice in a given situation.
- Anesthesiologists have the opportunity to impact surgical outcomes through hand hygiene. It is time to become educated and figure out how to implement convenient, effective hand hygiene in your own practice.
- Although glove use has been shown to decrease touch sensitivity, the benefits of their use should outweigh this concern. **But remember that gloves do not replace hand hygiene!**
- Mom was right: Wash your hands! Even if you don't know if the patient has an infection.

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# Remember That the Same Simple Mistakes at Induction (and Emergence) Happen Over and Over Again!

Brandon Dial, MD and Randal O. Dull, MD PhD

For the airplane pilot, the most critical moments of a successful flight are takeoff and landing. So it is with anesthesia—the most critical moments occur at induction and emergence of general anesthesia. Like the pilot with a preflight checklist, the successful anesthesiologist has a checklist of important items that are reviewed prior to every induction to avoid many of the common pitfalls that may occur at these crucial times. Preventable anesthetic mishaps are often caused by a lack of familiarity with anesthetic equipment and a failure to check the anesthesia machine for proper function.

## Induction

Although there are many such checklists, the following mnemonic has been used at our institution to help ensure that the anesthesia machine and other equipment are ready for use by the prepared practitioner.

S—Suction
O—Oxygen
A—Airway
P—Positive-pressure ventilation
M—Medications
M—Monitors

**S is for suction, probably the most easily and hence most commonly overlooked piece of equipment necessary for a successful induction.** Although it is not always used, its presence is crucial for patients at risk for emesis and aspiration of gastric contents. It should be turned on and readily available with an appropriate tip and suction strength (−125 to −200 cm $H_2O$). If you have checked your suction but then left the operating room (OR) for something, you must recheck it again right before induction.

**O is for oxygen.** The anesthesia machine should be checked to ensure that oxygen is being delivered from the wall outlets and that the flow meters for oxygen and air are working appropriately. A secondary source of oxygen should be available. This is accomplished most commonly by an auxiliary oxygen E-cylinder located at the back of the anesthesia machine. The valve should be opened and the pressure checked to ensure that it is full and ready for emergency use.

**A is for airway equipment.** Laryngoscope handles should be connected to blades to ensure that the light source is working. If it is not, the batteries or light bulb may need to be replaced. Several sizes of laryngoscope blades should be available, including both straight and curved blades. Despite the thorough preoperative airway exam, many difficult airways are realized after induction. Other airway devices such as oral and nasal airways for mask ventilation should be a close reach away. The Eschmann stylet (or Bougie) is a helpful airway tool for the unexpected difficult laryngoscopy. Assorted laryngeal mask airways should be ready for use. Other devices for the difficult airway are noted in the American Society of Anesthesiologists (ASA) emergency airway algorithm. These should be available and the practitioner familiar with their use, including supplies necessary to create a surgical airway. Preparation is paramount in the "can't intubate, can't ventilate" clinical emergency.

**P is for positive-pressure ventilation.** Failure to check the anesthesia machine for potential malfunction is a significant cause of anesthesia accidents. The anesthesia machine should undergo a leak test to ensure that positive-pressure ventilation can be provided reliably. Many newer machines have automated leak tests that require several minutes but minimal effort. In many older machines, a rapid leak test may be accomplished by turning the ventilator switch to the bag position, closing the adjustable pressure-limiting or APL valve (also known as the "pop off" valve) and occluding and occluding the circuit at the Y-piece, and then filling the breathing bag and circuit with the oxygen flush button to a level of 30 mm Hg. Maintaining a constant pressure with no leak is a rapid and reliable test that ensures your ability to deliver positive-pressure ventilation.

**M is for medications.** Induction drugs should be drawn up in sterile syringes. Double doses should be drawn of key induction agents in case they get dropped on the floor, the patient requires more, or a difficult intubation creates a prolonged induction process. **Never use anything that has been dropped on the floor**. Multidose vials should be cleaned with alcohol before needle insertion. Remember to clean the rubber stopper after removing the dust cover on new vials, as this cap does not guarantee sterility. Use a new sterile syringe for every dose of medication given. Most induction drugs and muscle relaxants are stable in syringes for 24 hours, but use beyond that period should be discouraged because the risk of bacterial contamination increases.

Obvious exceptions include propofol, which should be used within 6 hours after accessing the sterile vial. Emergency drugs for unexpected but common events such as hypotension should be readily available. Many of these emergency drugs (like atropine, lidocaine, and epinephrine) are now available as prefilled syringes that can be accessed and administered quickly when the clinical situation arises. Other key medications such as ephedrine and phenylephrine should be close at hand. Many practitioners also consider succinylcholine to be an emergency drug for rapid treatment of laryngospasm.

**M is for monitors.** Standard ASA monitors including blood pressure, pulse oximetry, capnography, and temperature monitoring are mandatory for every general anesthetic. Another key monitor during induction is the twitch monitor. Its use after administration of a nondepolarizing neuromuscular blocker will ensure optimal intubating conditions.

## Emergence

Avoiding common pitfalls during emergence from general anesthesia can be accomplished with a similar checklist.

Once again, **having suction at the ready can prevent many problems during extubation**. One of the most common causes of laryngospasm during emergence is pooling of secretions on the vocal cords. Patient transport at the end of a general anesthetic should include oxygen, whether or not extubation is planned. Check the oxygen E-cylinder to ensure that it has enough oxygen for the transport. An E-cylinder with 1,000 psig is half-full, and contains about 330 L of oxygen. If it is exhausted at a rate of 6 L/min, this amount will last 55 minutes.

After extubation, airway equipment including a mask and oral airway should be readily available. When transporting an intubated patient to the intensive care unit (ICU), a laryngoscope and an endotracheal tube should be brought for emergency reintubation if an unexpected extubation occurs. Positive-pressure ventilation can be given by way of a portable breathing circuit. Common examples used for patient transport include Jackson Rees circuits (Mapleson Class A) and Ambu bags that allow the delivery of positive-pressure ventilation.

Medications, including crystalloid fluids, are especially critical for the transport of an intubated patient to the ICU. Sedation and muscle relaxation may be important. Pressor agents and additional intravenous (IV) fluids should be available for patients with cardiovascular instability. Clinical circumstances may require the need for beta-blockade or other antihypertensive treatment, or narcotics for treatment of surgical pain.

Once again, the twitch monitor can be crucial to avoiding airway compromise from continued neuromuscular blockade if muscle relaxation was administered and extubation is planned. Its use can apprise you of whether reversal agents are needed and

the effectiveness of the reversal agent. This can help ensure that the patient wakes up without muscular weakness and airway compromise.

One last point for a successful takeoff and landing: **know your patient's name.** Your safe navigation of these critical tasks requires skill. Knowing your patient's name is part of the professionalism required of a perioperative physician.

## TAKE HOME POINTS

- Suction, suction, suction!
- Always have multiple laryngoscopes available.
- Double draw the crucial induction drugs—including, at a minimum, the induction agent and succinylcholine (if it is not contraindicated).
- Don't pick up anything from the floor and use it on the patient.
- Remember that emergence, in a sense, is induction in reverse. Redundancy of your critical components is just as important during this phase.

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# Smoking Cessation Part I—ANYTIME Is a Good Time to Quit

Yu Shi, MD MPH

Anesthesia providers frequently encounter surgical patients who are smokers in their practice. Despite significant public health progress in reducing the prevalence of smoking over the last several decades, 15% of adults in the United States are current smokers. An estimated 10 million smokers undergo surgical procedures every year. Cigarette smoking causes profound alterations in physiology that poses increased risk of pulmonary, cardiovascular, and wound complications in the perioperative period. Perioperative abstinence from smoking has both immediate and long-term benefits in patient's health. Anesthesiologists play an important role as perioperative physicians to help patient quit smoking for surgery.

## Smoking Increases Perioperative Complications

Chronic exposure to cigarette smoke is a major risk factor of coronary artery disease and vascular diseases. Smoking acutely increases myocardial oxygen consumption by increasing heart rate, blood pressure, and myocardial contractility. Nicotine increases sympathetic flow. Carbon monoxide shifts the oxyhemoglobin dissociation curve to the left, interfering with oxygen release. Therefore, smoking in the immediate preoperative period may increase acute cardiovascular risk.

Smoking is also a major cause of pulmonary diseases. Smoking causes an inflammatory state in the lung and induces structural damages and decline in pulmonary function. In the perioperative period, smoking is a risk factor for pulmonary complications, including bronchospasm and pneumonia. Second-hand smoke exposure in children is associated with upper airway complications.

Smoking causes impaired tissue oxygenation and affect the function of fibroblasts and immune cells. As a result, smokers are more likely to experience postoperative wound-related complications including dehiscence and infection. Smoking also impairs the healing of bones and ligaments.

A meta-analysis of 107 studies published in 2014 demonstrated that smokers had relative risks of 2.15 (95% confidence interval 1.87 to 2.49) for wound-related complications compared to nonsmokers, 1.73 (1.35 to 2.23) for pulmonary complications, and 1.60 (1.14 to 2.25) for admission to intensive care units. Study also found that current smoker had significant increase in healthcare cost compared to never smokers in the first year after surgery.

## Any Time Is a Good Time for Stopping Smoking

Abstinence from cigarette smoking decreases the risks in the perioperative period. The duration needed for the body to recover from the reversible effects of smoking varies. Current evidence suggests that it may take several months of abstinence prior to surgery to maximize the reduction in pulmonary complications. **However, it is NOT true that brief abstinence actually increases the risk of pulmonary complications.** This belief was originated from misinterpretation of an earlier publication and has now been debunked. There is also no evidence to support the idea that quitting causes transient increase in cough and mucous production. Because the many smoke constituents have short half-lives, **even brief abstinence from smoking is likely beneficial for surgical patients.** For example, carbon monoxide level falls rapidly within 12 hours after stopping smoking. The risks of acute ischemia may also quickly decrease as oxygen supply improves and myocardial oxygen demand decreases. Maximum exercise capacity is significantly improved after 12 hours of abstinence. Because of the significant improvement in tissue oxygenation, there is good reason to believe that even brief abstinence in the perioperative period would decrease wound complications. Even when a patient reports having last cigarette the morning of surgery, he or she should still be advised to stop smoking for at least the first week of surgery to allow healing process to happen.

**Surgery is a "teachable moment" for smoking cessation that motivates patients to change their behavior**. Undergoing a major surgery is associated with a two-time increase in spontaneous quit rate. Studies also showed that nicotine withdrawal does not always occur in the perioperative period. Therefore, surgery is an excellent time to quit smoking for good. Interventions occurring several weeks before surgery are effective in producing cessation at time of surgery and increases long-term abstinence rates. A recent meta-analysis concluded that intensive intervention (defined as multiple in-person counseling sessions started at least 4 weeks prior to surgery and usually involved drug therapy) reduces postoperative complications (risk ratio: 0.42, 95% CI 0.27, 0.65).

## How Could Anesthesiologists Help in Smoking Cessation?

Anesthesiologists should always ask about the smoking status of surgical patients and advise them to quit for as long as possible both before and after the surgery. Treatment of nicotine dependence involves both pharmacotherapy and behavioral interventions. Nicotine replacement therapy (NRT) is effective in promoting abstinence and has been approved safe in surgical patients and patients with cardiovascular diseases. Electronic cigarettes as a form of NRT are feasible and acceptable to patients who are scheduled

for surgery. Other drug treatments include bupropion and varenicline, both are effective in helping patient quit smoking and are safe in the perioperative period. Behavioral counseling requires special skills and time, which is not feasible to be delivered by anesthesiologists. However, anesthesiologist can refer patients to treatment programs offered by their hospitals or to telephone quitlines (1-800-QUIT-NOW), which is available in all states and provides treatment and follow-up to smokers at low or no cost.

## TAKE HOME POINTS

- The list of deleterious effects of smoking is long and comprehensive—cardiac, pulmonary, vascular, autonomic, and wound-healing status are all decreased by perioperative smoking.
- Smoke has numerous agents with short half-lives—even 12 hours of abstinence will benefit your patients. The full benefits of smoking cessation will accrue for several months.
- Recent smoking cessation **DOES NOT** cause an increase in airway reactivity and increased coughing and mucous production—that old information has been debunked.
- Do every reasonable thing you can personally and get your department to do everything they can to encourage and achieve perioperative smoking cessation. Educate your preoperative evaluation people with this chapter—literature, formal counseling, confidential chatting, medications—they are all worth consideration and in the best interests of your smoking patients. Smoking cessation is worth the extra time and effort you spend trying to get it done.

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# Smoking Cessation Part 2—So Good for the Patient as Long as You Understand the Effects on CYP1A2 Drug Metabolism (Especially R-Warfarin)

Catherine Marcucci, MD, Brian T. Gierl, MD, and Neil B. Sandson, MD

It is unfortunate that so many patients who present for surgery continue to smoke—it has been estimated that at least one-third (and probably closer to one-half) of various patient cohorts presenting for surgery are smokers. As discussed in Chapter 117, the benefits of smoking cessation for the presurgical patient are enormous. They include an immediate reduction in the overall rate of surgical complications, including cardiovascular, respiratory, and wound complications. Smoking cessations have also been associated with improved surgical outcomes in certain types of surgery such as urologic, plastics, and orthopedic procedures—so much so that it is a MIPS measure for anesthesia staff to cancel any elective surgery if the patient smoked that day (MIPS and MACRA are covered in Chapter 304). Multiple researchers and clinicians have developed and deployed a wide variety of both strategies and tactics to this end, with incomplete success.

As such, patients are usually counseled to stop smoking before surgery and may even be prescribed a nicotine patch or other medicines as therapy.

Certainly, a few patients achieve the recommended goal of smoking cessation 4 to 6 weeks before surgery, but by far the greater number do not manage to stop smoking until the day before or even the morning of surgery ("No, I don't smoke, I quit two hours ago"). It is important to remember that any degree of smoking cessation in the perioperative period is beneficial to the patient, especially to the pulmonary and cardiovascular systems. These include a decrease in blood carbon monoxide levels as well as a rightward shift in the oxygen–hemoglobin dissociation curve and an increase in tissue oxygenation. **However, anesthesia providers must be aware of the unintended consequences of smoking cessation—balanced against the obvious benefits is the fact that the polycyclic aromatic hydrocarbons in smoked tobacco act as strong inducers of the cytochrome P450 1A2 enzyme, moderate inducers of cytochrome P450 2E1, and inducers of some not-yet-well-characterized phase II enzymes. Abrupt cessation of smoking may cause alterations in the blood levels and/or end-organ effects of various medications, possibly in ways that could produce inconvenience or even harm to patients.**

Only smoked tobacco acts as an enzymatic inducer. Hookah or water pipe smoke has not been shown to impact P450 activity while "conventionally smoked" marijuana will

induce CYP1A2 (Remember that the cannabinoids themselves will also inhibit some P450 enzymes). It is not the nicotine component, but rather the polycyclic aromatic hydrocarbons that must be smoked in order to induce metabolic enzymes, so enzymatic induction does not occur with nicotine inhalers or vaping, patches, gum, or even chewing tobacco. The P450 1A2 enzyme catalyzes the metabolism of a number of substrates that are of clinical relevance in the perioperative period. These include cyclobenzaprine, flecainide, propranolol, theophylline, and R-warfarin (Table 118.1). In the days following smoking cessation, and resulting reversal of induction, the decreased availability of P450 1A2 decreases the metabolic clearance of these 1A2 substrates, leading to significantly increased blood levels. These increases in substrate levels can produce frank toxicity (such as with theophylline) and otherwise complicate perioperative management. There have been cases of increased bleeding attributable to smoking cessation in patients who take warfarin. The effects of smoking cessation may be mimicked by the abrupt introduction of inhibitors of P450 1A2, such as caffeine, cimetidine, ethinylestradiol, and many of the fluoroquinolones (Table 118.1). Other inducers of 1A2 (besides tobacco smoking) include carbamazepine, rifampin, and modafinil (Table 118.1).

**Table 118.1 ■ Drugs That Interact With Cytochrome P450 1A2**

| 1A2 Substrates | 1A2 Inhibitors | 1A2 Inducers |
|---|---|---|
| Caffeine | | |
| Clozapine | Caffeine | Carbamazepine |
| Cyclobenzaprine | Cimetidine | Modafinil |
| Flecainide | Ciprofloxacin | Rifampin |
| Fluvoxamine | Ethinylestradiol | Tobacco (smoked) |
| Haloperidol | Fluvoxamine | |
| Mexiletine | Grapefruit juice | |
| Olanzapine | Mexiletine | |
| Propranolol | Norfloxacin | |
| Tacrine | Ofloxacin | |
| Theophylline | Ticlopidine | |
| (R-)Warfarin | | |

Although smoked tobacco produces a less potent induction effect at P450 2E1 than at 1A2, smoking cessation can still lead to decreased metabolism and increased blood levels of notable cytochrome P450 2E1 substrates, including the "flurane" inhalational anesthetics.

Awareness of the pharmacokinetic issues arising from abrupt smoking cessation can help the careful clinician avoid drug toxicity that might otherwise develop in the perioperative period.

## TAKE HOME POINTS

- For the majority of smokers who present for surgery, the perioperative period is characterized by abrupt smoking cessation.
- The polycyclic aromatic hydrocarbons in smoked tobacco act as strong inducers of the P450 1A2 enzyme, moderate inducers of P450 2E1, and inducers of some not-yet well-characterized phase II enzymes.
- Abrupt cessation of smoking may cause alterations (increases) in the blood levels and/or end-organ effects of various medications. The plasma concentrations of substrates of P450 1A2, such as cyclobenzaprine, flecainide, propranolol, theophylline, and R-warfarin may increase dramatically, leading to toxicity. Warfarin is perhaps the one to be most aware of and concerned about. **If you are not now in the habit of scanning the drug lists of smokers for CYP1A2 inducers and substrates, you should start with your patients who are also on warfarin**. To go over one more time: the enzyme substrate is R-warfarin and the enzyme inducer is smoked tobacco of any type. When the patient stops smoking, you are removing an enzyme inducer, which will decrease metabolism of the certain drugs, including warfarin. This can lead to excessive anticoagulation.
- Re-initiation of smoking after discharge from the hospital will reinduce P450 1A2, leading to increased clearance of 1A2 substrates and a corresponding decrease in blood levels. In the days following reinitiation of smoking, dosages of 1A2 substrates that were decreased following smoking cessation will need to be increased to their original levels.

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# Flying to the Mayo Clinic for Surgery? The Clot Thickens

Misty A. Radosevich, MD, Abram H. Burgher, MD, and Juraj Sprung, MD PhD

Prolonged immobility associated with long-distance air travel predisposes patients to deep vein thrombosis (DVT) and venous thromboembolism (VTE). A long-haul flight of 8 hours or more increases the risk of thrombosis, with asymptomatic DVT developing in up to 10% of such travelers. The prolonged immobility and hypercoagulable state associated with major surgery may add to this risk. Therefore, patients who travel long distances to have surgery may be at high risk for perioperative VTE. Indeed, in a large retrospective review at Mayo Clinic, patients traveling before surgery more than 5,000 km had a higher rate (≈30×) of perioperative VTE than those traveling a shorter distance. In that study smokers and patients with a higher American Society of Anesthesiologists' (ASAs) physical status classification were more likely to be affected. VTE after long-haul flights can be recognized as long as 8 weeks after travel, but the highest incidence is in the first 2 weeks after travel. It should be noted that a similar increased risk of VTE has been reported after long-distance travel by car, bus, and train. Therefore, all perioperative physicians should be aware of this risk and must be ready to recognize even the subtle signs and symptoms of DVT and pulmonary embolism (PE) to avoid catastrophic perioperative complications.

Several mechanisms have been proposed by which long-haul air travel may contribute to the risk of VTE. Long periods of relative immobility (also called "economy class syndrome"), especially in patients sitting in nonaisle seats; obstruction of venous return as a result of compression of popliteal veins at the edge of the seat; exposure to hypobaric, low-humidity air; the stress of travel; hypercoagulability (seen even in healthy volunteers exposed to a simulated airplane cabin environment); and possibly dehydration resulting from decreased fluid intake or excessive use of alcohol during the trip, all may be additive risk factors. Additional risk factors specific to air travel are shown in Table 119.1.

Morbidity and mortality from VTE is attributable primarily to PE, which fortunately has a low incidence of 1.65 per million patients flying >8 hours to 4.8 per million

patients after flights >12 hours. PE is sometimes difficult to diagnose in the perioperative period because clinical manifestations are often nonspecific. Manifestations include dyspnea, substernal chest pain, syncope, tachycardia, or even cardiac dysrhythmias, and worsening of pre-existing congestive heart failure. Pleuritic chest pain and hemoptysis are seen only when pulmonary infarction has occurred. Physical examination may indicate lower-extremity swelling resulting from obstruction of venous outflow by thrombus in large vessels.

**Table 119.1 ■ Risk Factors for Venous Thromboembolism With Additional Risk Factors Specific to Air Travelers**

| Risk Factors for Venous Thromboembolism |
|---|
| **Age** |
| Older age, with increasing risk after age 40 |
| **Weight** |
| Body mass index >30 kg/m$^2$ (can be calculated as [mass in pounds × 703]/[height in inches]; see **www.nhlbisupport.com/bmi/**) |
| **Medications** |
| Women taking oral contraceptives or hormone replacement |
| **Medical or surgical issues** |
| Previous venous thromboembolism, either deep venous thrombosis or pulmonary embolism |
| Varicose veins |
| Medical illness (congestive heart failure, chronic obstructive pulmonary disease, stroke with paralysis, or paresis, pneumonia) |
| Pregnancy and up to 6 wks postpartum |
| Active cancer or cancer chemotherapy |
| Central venous catheter placement |
| Thrombophilia disorders, including factor V Leiden mutation, prothrombin G20210A gene mutation, protein C and S deficiencies, antithrombin deficiency, antiphospholipid syndrome, elevated levels of factor VIII |
| Recently bedridden more than 3 days |
| Recent cast immobilization or major surgery (within 12 wks before flying that required general or regional anesthesia) |
| Recent trauma within 3 mo (or anything that compresses the veins such as |

a hematoma or fracture)

**Additional Risk Factors Specific to Air Travelers**

**Height**

People who are under 165 cm (65 in or 5 ft 5 in) in height
People who are over 185 cm (73 in or 6 ft 1 in) in height

**Flight duration**

Single long-haul flights of more than 8–10 hrs
Multiple long-haul flights of at least 4 hrs
(risk may persist up to 8 wks after the flight)
More frequent flights of any duration within a short time frame
(i.e., days or 3 wks)

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Results of electrocardiography are altered in most cases, although abnormalities are often subtle and nonspecific. T-wave inversion in the precordial leads ("anterior ischemic pattern") is the most common finding in massive PE. Tachycardia and signs of right ventricular strain (right-axis deviation, peaked P waves, and ST–T-segment abnormalities) may be observed. When seen together, an S wave in lead I, a Q wave in lead III, and an inverted T wave in lead III are suggestive of PE. This "S1, Q3, T3" pattern has a sensitivity of about 50% for both massive and nonmassive PE.

Arterial blood gas analysis generally shows arterial hypoxemia with a widened alveolar-to-arterial $O_2$ gradient and respiratory alkalosis. Because of its high sensitivity (>95%), testing for elevated D-dimers may potentially be a useful preoperative screen for patients suspected of having VTE. However, because D-dimer levels can fluctuate widely in the postoperative period, this test is not likely to be of great utility immediately after surgery without corroborative evidence. Definitive testing for DVT or VTE can only be accomplished with duplex ultrasound, venous angiography, computed tomography, or pulmonary angiography (for PE only). Definitive testing may be merited in patients presenting with any of the above signs or symptoms, especially in long-distance travelers, a group known to have a higher probability of VTE.

Patients traveling long distances (especially overseas) before surgery should be made aware of the potential for increased risk of perioperative thrombotic complications. The stratified risk and prophylaxis for people undertaking a long-distance trip according to assigned risks are shown in Tables 119.2 and 119.3). All travelers should be advised to undertake maneuvers to prevent blood sludging in the

legs, including exercises in the seat and getting up and walking. While the role of hydration in prevention of thrombosis was not clarified, taking fluids will encourage trips to the toilet which will exercise the legs. There are additional recommendations for prophylaxis which may apply on high-risk travelers (Table 119.3). For those who are already taking anticoagulants (e.g., warfarin) and are in therapeutic range no further prophylaxis is required.

Because VTE is sometimes a difficult diagnosis to make in the perioperative period and its potential morbidity is so high, these patients should have careful perioperative surveillance. Unexplained hypoxemia, leg swelling, and electrocardiographic abnormalities are all alarming findings in a patient traveling a long distance for surgery.

**Table 119.2 ■ Risk Factors**

| Lesser Risks | Major Risks | Very High Risks |
|---|---|---|
| Hormone replacement therapy | Family history of venous thrombosis | Personal history of venous thrombosis, unless associated with an obvious precipitating event which has finished |
| Obesity (BMI >30) | Pregnancy or postpartum | |
| Visible (and troublesome) varicose veins | Age >60 yrs | |
| Inflammatory bowel disease | Recent surgery or limb immobilization (e.g., plaster cast) | |
| Age >40 yrs | Recent stroke | |
| Recent leg trauma | Know thrombophilia | |

Permissions obtained from http://www.anticoagulationeurope.org/advice/travellers-thrombosis.

**Table 119.3 ■ Prophylaxis Stratified According to Thromboembolic Risk Level**

| Lesser Risks | Major Risks | Very High Risks |
|---|---|---|
| Exercise legs, either while sitting or by walking<br>Keep legs straight<br>Avoid dehydration<br>Consider support stockings | All "lesser risks" measures + surgical support stockings | All "lesser risks" measures + LMWH – single SC injections at standard Veno-prophylactic dose, 2–4 hrs prior to travel<br>Avoid sleeping tablets |

Permissions obtained from http://www.anticoagulationeurope.org/advice/travellers-thrombosis.

## TAKE HOME POINTS

- VTE is not rare in long-haul air travelers—ask your patients how they traveled to the hospital, especially if you are at a tertiary referral center.
- VTE is more common in patients who are older, have higher ASA status, are obese, and who are smokers.
- Consider examining your patients specifically for signs of VTE in the immediate preoperative period.
- Patients traveling more than 500 miles by car on the day before surgery may warrant similar consideration.

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# Don’t Let Your Understanding of the Utility of Preoperative Stress Testing in Suspected Heart Disease Lapse

Matthew DeCaro, MD

Although stress testing is quite useful in preoperative cardiac risk stratification, it is a flawed modality.

There are several serious cardiac complications that can result from noncardiac surgery. These include ischemic events, arrhythmias—both brady- and tachyarrhythmias—and heart failure. Although stress testing can give some insight into an individual’s propensity for arrhythmias and heart failure, its role is limited. By and large, its main use is in the diagnosis of clinically significant coronary artery disease (CAD). Because the most catastrophic cardiac complication of surgery, myocardial infarction (MI), with the attendant permanent loss of cardiac muscle and thus function, is caused by CAD, much attention has therefore been focused on stress testing.

The sensitivity and specificity of exercise stress testing for diagnosing coronary disease varies with the severity of this disease. Table 120.1 gives average results for various severity subsets across studies.

As can be seen, the test is more useful in severe forms of CAD. It is in these patients that prior intervention (regardless of the proposed surgery) may improve survival. Remember that the greater the sensitivity of a test, the more useful it is for excluding a diagnosis when the test is negative. More specific tests help in establishing a diagnosis when the test is positive. The main utility of the stress test in the context of risk stratification for surgery is in excluding severe CAD in a patient with a negative test. To add to the confusion, many of these statistics are from specialized centers under controlled circumstances. Depending on the population studied, the accuracy of stress testing may be much poorer. In several community hospital studies in a general medical population, the sensitivity was substantially worse (<50%).

The posttest likelihood of CAD is highly dependent on the pretest likelihood. If the pretest probability of CAD is either very low or high, the test provides little additional information. A negative test in a 70-year-old hypertensive diabetic with typical anginal

chest pain is not helpful for excluding the diagnosis of CAD. It can be argued that it decreases the statistical chance of severe three-vessel or left main disease, but recall that one of the causes of a false-negative nuclear scan is global ischemia, usually caused by critical left main stenosis.

Unfortunately, although there is a general correlation between severity of CAD and operative morbidity and mortality, it is an imprecise predictor of acute coronary syndromes (ACSs). These include unstable angina, non–ST-segment elevation MIs (NSTEMIs), and ST-segment elevation MIs (STEMIs). It should be recalled that one is just as likely to experience an ACS from a plaque that results in an angiographic stenosis ≤50% as it is from a stenosis >50%. This is due to several factors. The primary factor that determines plaque instability is not the severity of the narrowing. Although the physical bulk of the plaque plays a role, other factors such as erosion of the fibrous cap overlying the plaque are more important. Vessel inflammation, of both the humoral and cellular components, is primarily responsible for the thinning, erosion, and ultimately rupture of this cap. This is the proximate cause of the ACSs. Hence, stress testing is an imprecise indicator of an imprecise predictor for ACS! Stress testing can be expected to be much better at predicting what it measures—namely, coronary stenoses of >70% that would produce flow-limiting ischemia, that is, angina pectoris triggered by physiologic stress.

**Table 120.1 ■ Average Results for Various Severity Subsets**

| | Sensitivity | Specificity |
|---|---|---|
| Single-vessel CAD | 68 | 77 |
| Multivessel CAD | 81 | 66 |
| Three-vessel/left main CAD | 86 | 53 |

CAD, coronary artery disease.

Pharmacologic testing is only slightly less sensitive and specific than exercise modalities, so the same analysis as above applies here as well. The major disadvantage of these techniques is the loss of clinical information related to the assessment of exercise capacity. This is actually quite meaningful information. The single best univariate prognosticator in many studies on stress testing is the number of minutes the individual can exercise on a symptom-limited test, even more useful in one study than the coronary anatomy at angiography.

## TAKE HOME POINTS

- Although stress testing yields some valuable anatomic and physiologic data, it cannot be relied on as the sole, accurate predictor of cardiac risk for noncardiac surgery.
- Many factors need to be factored together to arrive at an individual's risk. The intrinsic risk of the procedure to be performed and the urgency of this procedure are two important issues. In addition, an intervention as simple as the judicious use of beta-blockers in the perioperative period has been shown to reduce morbidity and mortality in certain at-risk patients.
- The risk assessment of an experienced clinician, combining clinical data obtained from a careful history and physical examination, determination of the traditional risk factors for CAD, functional capacity in daily living, analysis of left ventricular function, supplemented where appropriate by noninvasive and invasive testing for coronary disease, should be considered the "gold standard" for preoperative evaluation.

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# A Positive Troponin Does Not Always Mean a Myocardial Infarction—Will the New High-Sensitive Assays Help Sort It Out?

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A common scenario in the preoperative evaluation of an acutely ill patient is the discovery of a positive troponin. Although this is commonly interpreted as a sign of myocardial ischemia, this may or may not be the case. Positive troponins occur without myocardial infarction (MI) in several situations that have implications for perioperative care very different than those of active MI. Troponins I, T, and C form a complex with actin and myosin and control contraction in cardiac and skeletal muscles. A small amount of cardiac troponin is cytoplasmic, whereas the rest is sarcomeric. Although cardiac and skeletal muscles share isoforms of troponin C, cardiac troponins I and T are distinct from skeletal isoforms.

## Troponin Assays

Since the year 2000, the international consensus definition of MI has included positive troponins with gradual rise and fall, and clinical evidence of MI (characteristic electrocardiogram changes or ischemic symptoms). Within 3 years of the introduction of this definition, the incidence of emergency department–diagnosed acute MI increased nearly 200%. Clearly, troponin values are sensitive tools to diagnose myocardial ischemia, but this sensitivity has posed some problems. The value of this test led to the marketing of a large number of diagnostic assays, which have improved significantly since their introduction; early assays were less specific for cardiac troponins. The variety of assays means that clinical labs at different institutions must promulgate their own norms; values must be interpreted relative to the local reference values. It is not unheard of for neighboring institutions to have upper limit of normal values that differ by an order of magnitude.

The earlier nonspecific assays created confusion when emergency departments began using them in patients with low pretest probability of MI. What appeared to be spurious positives were found to be quite common. Although the newer assays are more specific,

there are still disease states other than acute MI that can elevate blood levels of cardiac troponins T and I. Familiarity with these states can prevent embarrassing mistakes, complications, and unnecessary case cancellations.

The last 5 years have seen the development of a high-sensitive cardiac troponin (hs-cTnT) assay, which has been available for several years in Europe but was only approved for use in the United States in early 2017. Although this assay is not yet in ubiquitous use, it will undoubtedly become more widespread. In cases of suspected acute MI, it improves the overall diagnostic accuracy. A negative result carries a highly negative predictive value and an MI can be ruled out with the first blood draw after chest symptoms if the values are very low. Of course, the gain in sensitivity comes with the downside of a loss in specificity. The increased specificity may be clinically important for patients who have a short elapsed interval from onset of symptoms to admission for acute coronary syndrome (ACS), stable coronary artery disease, and heart failure.

## Renal Failure

Chronic renal failure patients represent the largest group of patients who may have elevated troponins in the absence of acute myocardial ischemia or infarction. With newer assays, up to 50% of chronic renal failure patients without acute myocardial ischemia (based on clinical signs and electrocardiogram) have elevated troponin T. Troponin T is more frequently elevated than troponin I in this population, leading to speculation that troponin I is more specific; this speculation is not evidence-vetted, however. The mechanism for this finding is not yet clear. Troponins are large molecules that are cleared by the reticuloendothelial system and not the kidney, and troponin levels are not related to creatinine, blood urea nitrogen (BUN), or calcium phosphate product. Most of the evidence point to a cardiac source, whether that be clinically silent microinfarction, myocardial strain from heart failure, or alteration in expression of troponin molecules by renal failure. Regardless of this, what is known is that even in renal failure patients without active MI or coronary artery disease confirmed by angiography, positive troponins are a risk factor for intermediate and long-term mortality. And further, the increase in mortality is from all-cause mortality, not just cardiac death. The perioperative implications of this finding are not clear but are likely different from those of a patient undergoing surgery in the midst of an acute MI.

## Other Disease States

Other disease states that have been observed to elevate troponins without other evidence of acute myocardial infarction include congestive heart failure (CHF), left ventricular hypertrophy, supraventricular tachycardia, pulmonary embolism (PE),

cardiac surgery, cardiac trauma, defibrillation and cardioversion, sepsis, subarachnoid hemorrhage, cocaine use, methamphetamine use, and endurance running. This is by no means an all-inclusive list. What these things have in common is direct oxidative stress to myocardiocytes or overt necrosis and apoptosis—without occlusion of a large coronary artery. With the exception of marathon running, all of these states are known to have the potential for lasting cardiac effects, and in the case of PE, CHF, and sepsis, studies have shown that elevated troponins portend worse outcome.

## Clinical Context—Cardiac Troponin Versus High-Sensitive Cardiac Troponin

So, unless your patient has recently run a marathon or been cardioverted, if the troponin is positive, it's probably a bad sign. Is the patient having an MI though? The diagnosis of MI by troponins requires the characteristic rising and falling of troponins; this usually occurs over a 24-hour period and thus sequential values are needed. They are generally drawn every 8 hours. This definition also requires other evidence of MI: ST changes, new Q wave, or ischemic symptoms. Patients who have positive troponins with appropriate kinetics and electrocardiogram changes or ischemic symptoms are having an acute MI. These patients have very high perioperative risk, and all but the most critical emergency surgical intervention should be postponed. Patients with chronic renal failure and chronically elevated troponins, or critically ill patients with elevated troponins with no new evidence of myocardial ischemia, may not be having an acute MI. Although a positive troponin in this setting has adverse intermediate and long-term prognostic impact, it probably does not carry the same level of perioperative risk as an active, acute myocardial infarction.

The clinical context is a bit different for the high-sensitive cardiac troponin assay. One large retrospective study was done in Israel. The aim of the study was to assess the frequency of both elevated hs-cTn levels and dynamic changes in medically complex hospitalized patients.

Hs-cTnT levels were obtained in 5,696 admissions and were above the 99th percentile (≥13 ng/L) in 61.6% of the measurements. A relative change of 50% or higher was observed in 24% of the admissions. However, among those with elevated hs-cTnT levels, ACSs accounted for only 6.1% of acute diagnoses. Maximal hs-cTnT levels above 100 ng/L, but not dynamic changes, discriminated between ACS and non-ACS conditions (positive and negative predictive values of 12% and 96%, respectively). Of interest to the investigators was the strongly positive predictor of 30-day mortality in patients whose hs-cTnT levels were about the 99th percentile, regardless of ultimate diagnosis.

## TAKE HOME POINTS

- Elevated cardiac troponin is present in acute MI.
- Elevated cardiac troponin is present in disease states other than MI.
- Chronic renal failure patients often have elevated troponin without other evidence of acute MI.
- The diagnosis of MI by troponin traditionally required a rise and fall as well as clinical evidence of ischemia.
- Hs-cTnT assay was recently approved for use in the United States. It has several advantages, including a strong negative predictive value if the levels are very low at the first blood draw. The assay has low specificity for ACS versus non-ACS.
- Troponin is the preferred biomarker for the diagnosis of acute myocardial infarction but must be understood in the clinical context.
- We recommend that you follow the hs-cTnT literature closely. Data for hs-cTnT assays lack definitive outcomes studies at present, but approval for the technique was eagerly awaited by cardiologists in the United States and they will almost certainly become more common as the clinical context is better understood. This will benefit the patients and several medical specialties, including ours and the cardiologists, who spend a significant part of their consultation time on the value and meaning of an elevated troponin value.

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# Preoperative Anxiolysis: It's Not Just "Two of Midaz"

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William Thomas Green Morton did not meet his patient before their encounter in the Ether Dome on October 16, 1846, as he was running late. Robert Hinckley's painting of the scene depicts an anxiety-producing environment—the patient strapped to a chair, the focus of attention in an auditorium full of surgeons. Gilbert Abbott might have benefited from 2 mg of midazolam, had it been available; but perhaps he would then have been unable to tell the audience, as he did immediately postoperatively, that the operation had been painless. As far as history records, his perioperative experience was satisfactory to him, entirely without premedication or a preanesthetic interview. Nonetheless, the preoperative anxiety of Gilbert Abbott and that of modern patients has implications for patient satisfaction and for patient care and physiology. Preoperative anxiety is common —conservatively 25% and up to 80% in some studies. Concerns associated with anxiety include postoperative pain, incapacitation, and death. Preoperative anxiety is correlated with delayed gastric emptying, with increased intraoperative heart rate and anesthetic requirements, and with increased postoperative pain scores.

## Recent History

It remains unclear what preoperative strategy is most effective, in most patients, in reducing perioperative anxiety. Based on a 1997 survey, most US anesthesiologists give anxiolytic medication as part of this therapy, but there are significant geographic, patient age, and hospital size variations. There is no consensus in the literature, and the number of regimens investigated is large and diverse. What is most clear is that patients have increased anxiety before operations and interventions performed by anesthesiologists can reduce that anxiety.

An often-cited study purporting to show that the anesthetic interview is more effective than pentobarbital premedication was performed in 1963, but this study was methodologically flawed. The most anxious patients (those who kept the interviewer past the allotted time) were dropped from the study, but only in the interview arm. There

was no assessment of baseline (prehospital) anxiety and no objective measure of anxiety. All patients received intramuscular atropine before assessment, patients were not aware they were part of a study despite being administered study medications, and it is unlikely that it is possible to blind an observer to whether a patient has received pentobarbital, as investigators claimed to have done. The literature on premedication and preoperative anxiolysis is rife with similar methodologic problems (although, thankfully, not the absence of consent). However, at least one well-designed study shows that a visit from an anesthesiologist can play a significant role. In a 1977 study conducted in Britain, Leigh et al. used an objective psychometric questionnaire to assess baseline preoperative anxiety and that after no intervention, a preoperative visit, or viewing a 10-page booklet on anesthesia. All patients had more than normal anxiety preoperatively. The preoperative visit was significantly more effective in reducing anxiety than the booklet or no intervention.

## Basic Principles

Although the content and tone of the preoperative visit have not been objectively evaluated, several basic principles of physician–patient interaction apply. There is no other physician–patient interaction in which the conscious, competent patient has greater reason for anxiety and is meeting a physician for the very first time. Patient concerns and anxiety must be taken seriously. Although some of these concerns may seem trivial or unusual, they are foremost in the patient's mind and need to be addressed with compassion. An example is fear of intraoperative awareness.

Anesthesiologists know that intraoperative awareness is an extremely rare event, that it is almost never complete awareness, and that it is associated with certain situations and kinds of anesthetics. Laypersons do not have access to this knowledge, and the only information to which they may have access (perhaps a television program or a magazine article) will have presented a population in which 100% of subjects ("victims" or "survivors") are affected with the most extreme awareness and are hurt or disabled as a result. It may be a challenge to encourage patients to believe an unknown, new authority rather than one they trust and with whom they are familiar. No pharmacologic agent can substitute for this process; one must simply pay serious attention to patients, gain their trust, and state clearly that it is the anesthesiologist's central concern to assure their safety and comfort. Indeed, amnesia produced by preoperative medication may erode some of the benefit of such a conversation if it is not remembered postoperatively.

## Patient Concerns

The obligation to take patient concerns seriously does not end on leaving the preoperative area. Patients en route to the operating room often express fears they may

have been unwilling to voice in the presence of family or friends. These "corridor concerns" may be trivialized by the setting, but to the patient they may have the gravity of "last wishes," as they know their next experience will be anesthetic induction. If necessary, one should stop patient transportation long enough to confront these fears. In the operating room, in the bustle of activity before induction, patients may again express fear or discomfort resulting from cold, monitoring equipment (tightness of a blood pressure cuff, for example), or claustrophobia from the mask. Patients will express anxiety about "misbehaving under anesthesia" or not having their dentures. Again, these concerns must be taken seriously. Each anesthesia provider eventually develops an individual style, but the fact that the patient's concern is taken seriously may have more effect than alleviating the discomfort that provoked it and probably is not dependent on any one thing the provider says. Tell patients that warm blankets are on the way, allow patients to hold their own mask, let them know that the blood pressure cuff is the cause of their arm discomfort and that the discomfort will go away. Ask if there is anything the staff can do to make them more comfortable before getting started, then tell them you are getting started, and that they are doing well. Children who have access to their parents during induction may have less anxiety, although at least one study has shown no difference between patients given premedicants and those with parental presence at induction. It is most likely that this is a function of population and that some children benefit from parental presence more than others.

## Pharmacologic Interventions

Although the presence of the anesthesiologist is a significant factor in reducing preoperative anxiety, many other interventions may be useful. Most commonly, preoperative medication is employed. Midazolam is commonly used because it is relatively short-acting, has amnestic properties, is anxiolytic, and is available in an oral form that can be given to children. In addition, midazolam appears to decrease the risk of nausea and vomiting, decrease blood pressure, improve postoperative pain control, and improved patient satisfaction. Other benzodiazepines are used, but their properties as preoperative medications differ. Lorazepam has the specific disadvantage of producing prolonged (up to 24 hours) cognitive dysfunction, most commonly in the elderly. Two studies show increased postoperative pain scores in patients who received preoperative diazepam. Many other classes of medication are employed for preoperative anxiolysis. Clonidine and dexmedetomidine have been shown to reduce postoperative pain scores and intraoperative heart rate and blood pressure. Anticholinergics, butyrophenones, opioids, barbiturates, antihistamines, and antiseizure medications have all been used to reduce preoperative anxiety and have specific roles.

## Nonpharmacologic Interventions

Finally, there are many other nonpharmacologic preoperative interventions that may reduce patient anxiety. For children, video games, video glasses, and even the presence of a clown-dressed anesthesiologist are reported to reduce anxiety. These interventions, unfortunately, have not been studied in adults. Music, either of the patient's choosing, or of a "soothing" nature, has been shown to reduce preoperative anxiety as reported by the patient, as well as intraoperative bispectral index scores and anesthetic requirements. Physical correlates of anxiety such as plasma catecholamine levels and blood pressure are unchanged by music, but it certainly does not hurt.

Binaural beats are apparent sounds produced in the brainstem (and perceived in the brain) when two sounds of similar frequency are presented separately to each ear. These binaural beats are auditory brainstem responses that, if stimulated (by being embedded in music, for example), can produce varying effects on EEG activity and arousal. A few studies have shown that binaural beat-induced brain wave states associated with relaxation (like delta waves) can reduce perioperative anxiety. This method has no appreciable risks, except perhaps the risks of missing out on the other (possible) benefits of pharmacologic anxiolysis as described above. Hypnosis and meditation may also be able to reduce preoperative anxiety, but it is unknown how these interventions may affect the intraoperative course or postoperative recovery. Such a nonpharmacologic method could conceivably be preferable in patients at risk of complications from common medications such as benzodiazepines—for example, the risk of delirium in the elderly or delayed PACU discharge in the outpatient setting. However, this has yet to be studied.

## Acupuncture

Probably the mostly studied nonpharmacologic approach to preoperative anxiolysis is acupuncture and its varying forms (acupressure, electroacupuncture, etc). A full review of the acupuncture literature is beyond the scope of this chapter, but in general, well-designed, well-controlled studies are difficult in acupuncture investigations, as it is challenging (though not impossible!) to blind both the patient and the practitioner. A common theme among the most rigorously controlled studies of subjective outcomes (i.e., pain, nausea) is that it doesn't matter where needles are placed (on so-called meridians or not), if needles break the skin, or even if needles are used at all (well-done sham protocols). However, these well-designed studies do show that both sham acupunture and true acupunture work better than no therapy (or sometimes standard therapy)—suggesting the effect of acupuncture is either just as good as, or due to, the placebo effect. While the subjective conditions that commonly occur in the perioperative setting—pain, nausea, and anxiety—are especially susceptible to the

placebo effect, this effect is real, can be powerful, and should not be discounted! The relatively minimal risks of acupuncture (though not risk free) may make this a desirable alternative to, or addition to, medications for preoperative anxiolysis.

## Summary

It is clear, certainly to patients, that preoperative anxiety is an important component of the perioperative experience. There are many effective interventions that may reduce this anxiety and lead to improved patient satisfaction. Most important of these is the compassionate understanding of a concerned anesthesiologist. Many medication regimens may be employed to augment the anxiolysis of physician counseling, and other interventions such as music, hypnosis/meditation, or parental presence for children may be helpful.

### TAKE HOME POINTS

- Preoperative anxiety is common and distressing to patients.
- Preoperative anxiety may have deleterious physiologic effects intraoperatively.
- Patient concerns must be taken seriously and assuaged compassionately.
- A visit from an anesthesiologist is an effective way to reduce anxiety.
- Preoperative medication, music, hypnosis, meditation, and other interventions may all be effective in reducing preoperative anxiety.

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# Schizophrenia Is a Devastating Mental and Medical Illness—and These Patients Have Significantly Greater Perioperative Risks Than Age-Matched Controls

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Schizophrenia is one of the most baffling, awful, and pernicious diseases that afflicts humankind. It occurs in about 1% of all adult patient populations. Schizophrenia is characterized by exacerbations of psychotic symptoms (delusions, hallucinations, and thought disorder) and a characteristically relentless downward trajectory in socioeconomic and overall health status. Schizophrenia is treated primarily with pharmacotherapy. The antipsychotic drugs range across a number of chemical classes, but generally tend to block the dopamine-2 receptor. Electroconvulsive therapy (ECT) is not a primary modality, so you will generally not see the schizophrenic patient in the ECT suite, but rather in the operating room, burn unit, and other intensive care units. Ironically, acute medical illness sometimes acts as an "organizing" influence with respect to the patient's mental status. So you may see the diagnosis of schizophrenia in a long list of premorbid conditions, but the patient seems to be rational and "making sense." The issue at that point is not to overestimate the patient's true baseline medical status and underestimate his or her perioperative risks. And remember, schizophrenia is a disease with fairly well-defined and specific criteria, it's not a catchall or "not otherwise specified" diagnosis. If the diagnosis of schizophrenia appears in the patient's history, it's generally there for a good reason.

## Preoperative Risk Factors and Evaluation

A large body of evidence has demonstrated that schizophrenic individuals are afflicted with a wide array of medical problems. Some of these issues are likely due to genetic abnormalities that are associated with schizophrenia. Other medical concerns develop as a result of poor attention to self-care and inconsistent medical follow-up that arise from the hypofrontality/negative symptoms that actually generate most of the longitudinal

morbidity of schizophrenia. Schizophrenic patients are also more likely to engage in lifestyle behaviors that affect their health status adversely, such as poor compliance with medications and/or perioperative instructions, smoking, poor dietary intake, and use of drugs and alcohol. It is also likely that metabolic syndrome arising from the use of antipsychotic medications contributes to this greater prevalence of medical comorbidities. Taken together, these medical issues significantly increase operative risk in schizophrenic patients.

It has been estimated that schizophrenic patients have a 20% shorter life expectancy than age-matched controls. Another study found that schizophrenia is associated with a greater prevalence of heart disease, chronic obstructive pulmonary disease, hypertension, and diabetes. Some research suggests that there are increased rates of hyperglycemia and diabetes, hyperlipidemia, hypercholesterolemia, and obesity that occur as intrinsic, associated features of this illness. Obstructive sleep apnea is especially prevalent among schizophrenic patients. The operative risks posed by these problems are only exacerbated by the tendency for schizophrenic patients to neglect their own care. These metabolic abnormalities are allowed to persist without medical intervention far more frequently than is the case in the general population. Thus, progression to significant cardiac, pulmonary, and renal pathology is more frequent, leading to greater operative risk.

The psychotic/positive symptoms (delusions, hallucinations, and thought disorder), as well as the interactive passivity of negative symptoms of schizophrenia, may well impact upon the schizophrenic patient's ability to give informed consent for anesthesia. For example, if a schizophrenic patient refused to give anesthesia consent because of his belief that the administration of anesthesia represented a clever sham during which the true objective of implanting monitoring devices could be accomplished, then this paranoid delusion would deprive this individual of the capacity to either consent or refuse anesthesia, and a surrogate decision maker would need to be consulted. Schizophrenic patients clearly present anesthesia providers with "curve balls" that they may not otherwise encounter regarding consent. Psychiatric consultation can be very helpful in navigating these challenging waters, but it bears mentioning that the four core elements of determining capacity to consent for anesthesia are exactly identical to those for a nonschizophrenic individual. These four core elements are: (1) ability to make a choice, (2) ability to understand relevant information, (3) ability to appreciate the situation and likely consequences of choices, and (4) ability to manipulate information in a rational manner.

## Intraoperative Management

Schizophrenic patients are thought to be at increased risk for a number of deleterious

events such as hypotension and hypothemia during anesthesia. To our knowledge, there are no conclusive practice guidelines as to which anesthetic agents are preferable. However, a recent Japanese article suggested that postoperative confusion was lessened with anesthetic techniques that utitlized ketamine, propofol, and fentanyl to minimize postoperative confusion. The same article suggested that epidural anesthesia with local anesthetics was effective in minimizing the risk of postopertive ileus in schizophrenic paients.

## Postoperative Risk Factors and Management

Postoperatively, schizophrenic have been suggested to be at increased risk for confusion, ileus, and thromboembolism. The etiologies for these postoperative complications are multifactorial but may arise from elevated cortisol, norepinephrine, and cytokine levels. Postoperative pain management may be complicated by the fact that schizophrenic patients sometimes have higher-than-expected pain thresholds.

## Antipsychotic Drugs

Although antipsychotic drugs are essential in the management of schizophrenia, the vast majority of these agents have been implicated in generating many of these metabolic and medical abnormalities. Thus, these drugs can exacerbate the risks that already arise from the illness itself. Additionally, antipsychotic agents often increase the length of the QT interval, yielding a greater risk of malignant arrhythmias, including torsade de pointes. Thioridazine and pimozide are low therapeutic index drugs that are malignant QT-prolongers. Pimozide has such a strong association with torsade de pointes that we feel that nobody should be on it unless it is absolutely necessary. The atypical antipsychotic drug clozapine, generally reserved for treatment-resistant schizophrenic patients, has been associated with myocarditis as well as significant lowering of the seizure threshold.

In summary, although it may seem counterintuitive or irrelevant to the core symptoms that define schizophrenia, it is important to keep the greater prevalence of medical comorbidities in mind when assessing operative risk in this patient population.

### TAKE HOME POINTS

- Besides the obvious mental health issues, schizophrenic patients warrant careful attention to their medical status.
- The increase in perioperative risk is multifactorial.
- Preoperative risks include diabetes, smoking, poor diet, poor adherence to medication plans, obesity, and hypertension.

- Be aware that sleep apnea is especially prevalent in schizophrenic patients. An anecdote from the author: It was a great relief for everybody (patients and staff alike) when the "dorm rooms" housing six patients were eliminated from the modern psychiatric hospital layout. "In the old days," it was not unheard of to have six large, male, schizophrenic patients, all of whom had gained 30 lb from their atypical antipsychotic medications, all suffering from a degree of sleep apnea, disrupting each others' sleep, and making it difficult for anyone to get rested and/or well.
- Schizophrenic patients are evaluated for competency in exactly the same qualitative fashion that nonschizophrenic patients are. Keep in mind, however, that extra time may be required, as well as the assistance of the psychiatric consultation–liaison service.
- Intraoperative risks include hypotension and hypothermia.
- Postoperative risks include delerium and ileus.
- Antipsychotic medications are implicated in a number of serious drug effects and drug–drug interactions. Perhaps the most important are those involving QT-prolongation and/or torsade de pointes.

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# What to Do About the Tattoos and Body Jewelry

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Tattoos have become increasingly common, with as many as 40% of adults in the United States aged 18 to 29 report having a body tattoo. Although wearing jewelry on the fingers and ears has a long history, body jewelry is now frequently also found in relatively novel anatomical locations. Management of the patient with tattoos, piercings, and body jewelry is therefore a common issue for the anesthesiologist; especially here in Portland, Oregon, as well as other many other locales with an active body modification culture. Unfortunately, there are little hard data and there is no firm consensus on management of these patients. Here we present some of the issues surrounding their care, and practice suggestions.

## Tattoos

The process of tattoo placement involves deposition of permanent pigment in the dermis using a needle. Common pigments may contain inorganic substances such as titanium, chromium, cadmium, iron, heavy metals, or other compounds; or organic substances such as carbon black, polymers, or organic dyes. The anesthesiologist will generally not be able to deduce the chemical composition of any given tattoo, as manufacturers of tattoo ink often consider their formulations proprietary, and some tattoos may be made by nonprofessionals using noncommercial dyes and contain metallic particles that could heat with MRI exposure. Pigments are also generally combined with an ink carrier, such as ethyl alcohol, which helps to disperse the pigment.

After placement, there is a robust immune response to tattoo ink. Ink is engulfed by local macrophages and can be found in regional lymph nodes, in some cases mimicking the appearance of melanoma. Recently placed tattoos (<4 weeks old) have ongoing inflammatory processes and infection at the site is common.

While there are a number of potential health complications from tattoo placement, from the perspective of the anesthesiologist the primary concern is whether it is safe to introduce a needle through a tattoo. In particular this is a concern during epidural

access. Risks from needle placement include coring and channeling. Coring involves shearing a portion of the skin, in this case by a Tuohy or spinal needle, and carrying this material into deeper structures. Of note, stylets in Tuohy needles do not eliminate the risk of coring. Channeling involves the creation of a tunnel by a needle or catheter from the skin to deeper structures, which could ultimately serve as a migratory path for foreign substances or microorganisms. Either of these mechanisms could introduce inflammatory material or infectious agents into sensitive structures such as the epidural space or other deep structures.

We were unable to find any case reports of neurologic complications of epidural placement through a tattoo, in contrast we were able to find several case reports of uncomplicated epidural placement, and a search of PubMed finds 11 different publications in two different languages that discuss the theoretical risk of introducing ink components to the neuraxial space. We conclude that the French have more tattoos than we had ever realized. Nevertheless there is a theoretical risk of neurologic complications due to an epidural placement via a tattoo, and therefore we would recommend the following:

- Informed consent should include a discussion of the theoretical risk posed by skin tattoos in the setting of neuraxial access, this discussion should be documented.
- Avoid neuraxial access through skin with a recently placed tattoo (<2 weeks).
- Regardless of the tattoo's age, perform careful inspection of skin looking for signs of infection or inflammation as the tattoo could conceal some of these signs.
- If possible, avoid needle insertion in areas with ink. This might necessitate using a paramedian approach or seeking a different vertebral level. Skin traction to displace the tattoo could also be used if done carefully.
- If it is impossible to avoid needle insertion in an area with ink, nick the skin with a scalpel prior to inserting the needle or make an initial skin insertion with another needle, as this will minimize coring.

## Piercings and Jewelry

In addition to the fingers and ears, common locations for jewelry include eyebrows, nose, cheeks, lips, tongue, nipple, navel, and genitals; jewelry may also be placed subdermally. Some of these sites are not readily visible during a routine preoperative physical exam, hence it is important to include this question in your history taking. In an obtunded patient your physical exam should include a survey looking for piercings and jewelry.

Potential perioperative complications from jewelry include:

- Jewelry becomes dislodged and is lost inside the patient (e.g., tongue ring is dislodged and aspirated).

- Jewelry becomes caught on OR equipment (finger ring catches on the OR table, tongue ring catches on laryngoscope blade, etc.) and the patient is injured.
- The intense electromagnetic fields present during electrocautery or in an MRI scanner can cause heating or even sparks to emanate from metallic jewelry, injuring the patient. In addition, ferrous jewelry can become a projectile in an MRI.
- Jewelry may create imaging artifacts during CT scans or other x-rays.
- Patient positioning on an item of jewelry can cause a pressure injury.
- Jewelry around the airway may bleed during airway manipulation, obscuring the airway; swelling or dental injury may also occur.
- Jewelry can become dislodged and lost somewhere in the perioperative area.
- Urologic injury can occur during attempted Foley catheterization of a patient with genital piercings. The use of smaller Foley catheters or preprocedure voiding might be helpful in the presence of such piercings.

The simplest way to avoid these complications is to remove the jewelry. Unfortunately, some patients will refuse removal of body jewelry prior to surgery for multiple reasons which could include religious or sentimental reasons, or concern about tract closure. Alternatively they may claim that they are physically unable to remove the jewelry.

The risks associated with leaving the jewelry in place need to be balanced with the benefits of proceeding with surgery. Some practitioners would cancel elective surgery under these circumstances, while others would proceed. If the decision is made to proceed, proper informed consent needs to include a thorough discussion of the risks posed by piercings and jewelry.

Removal of body jewelry can be anything from straightforward to very difficult. In extreme cases jewelers or medical professional may need to cut off a piece of jewelry. Having the patient remove the jewelry is typically the safest option, as the patient is often more familiar with the removal techniques for personal jewelry. In the case of an obtunded patient, or a patient who cannot physically remove their own jewelry, removal should be carried out by providers with proper training on how to remove and store jewelry. Of note, for patients concerned about tract closure, some anesthesiologists have advocated inserting a nonconducting catheter and tying it off to prevent dislodgement (see below).

Preoperative management of piercings is summarized below:

- Include questions about existing piercings in your preoperative history and physical exam.
- Include discussion about the perioperative risks posed by piercings in your informed consent. Remember, even after removal of jewelry the patient still has some risks like loss of patency of a piercing, infection, injury, and skin breakdown.

- Ask the patient to remove their jewelry. The patient is usually the most familiar with the easiest removal technique. Do not assume you are familiar with all piercings as improper removal technique could lead to injury to the patient or provider. Seek formal training in the management of piercings when available.
- Subdermal jewelry may not be removable except with excision or punch biopsy.
- If jewelry cannot be removed and the anesthesiologist nevertheless wishes to proceed with surgery, it is common practice to cover the jewelry with tape in an attempt to minimize the risk of the jewelry catching on something or heating due to electrocautery. However, the evidence base for this practice is quite scant.
- Piercings in highly vascular areas like the tongue tend to lose patency the fastest and might require retainers. A reasonable attempt to maintain piercing patency can be attempted at the provider's discretion. Techniques include patient replacement of metal jewelry with plastic or silicone retainers prior to surgery, or in emergent cases, a piece of IV or epidural catheters can be inserted in the piercing, and then suture thread passed through the catheter. The catheter can then be removed over the thread and the thread tied in a knot. The suture thread can be used as a guide wire for reinsertion of the original jewelry.
- Forceful attempts to remove jewelry, including cutting the jewelry, should not be attempted unless the anesthesiologist is specifically trained in the technique.
- Respect the patient's potential sentimental attachment to their piercings, body arts, or accessories.

## TAKE HOME POINTS

- You will encounter tattoos and piercings in your practice, no doubt about it. If you are a beginning clinician, start formulating your own practice paradigm now with respect to these issues. Talk to senior clinicians. There is a range of personal experience out there, from never having seen a "jewelry complication" to having seen a patient almost lose a finger from a refusal to remove a wedding band. The authors and editors employ a variety precautionary practices and range from "conservative" to "liberal" even among ourselves.
- Work with your preoperative clinic to establish preoperative instructions that pertain body jewelry. Respect your patients' jewelry attachments and use that point to stress to the patients that their jewelry is safest at home or with the family members in the waiting room.
- Sometimes, however exceptions are made for religious jewelry, such as a St. Christopher medal, that the patient wishes to wear during surgery. In that case, work with the patient to find a way that they can stay "connected" to their religious item, either physically or symbolically, while minimizing risk. For example, one of the

editors had a patient who was experiencing significant distress at not wearing his religious emblem around his neck on a short chain during an operation in which his face, neck, and torso were going to be draped and turned 130 degrees away from the anesthesia team. However, he agreed to have the emblem sutured to a wide, soft, stretchy knit headband that we placed on an arm that we could access and see on an arm board and the surgeons were happy to sew it up for us to get the case moving.

- Make sure you are onboard with the surgeons with respect to jewelry. You don't want conflict on these issues right before going into the operating room. We have noted that sometimes surgeons become a little bit more adamant about requiring the removal of all jewelry as they get more experienced, especially the soft tissue and plastic surgeons.
- Jewelry that the patient can't take off is a bit more of a problem than jewelry they don't want to take off, especially if the ring or bracelet has become too small.
- Proceed cautiously with a plan to "soap off" a ring on an anesthetized patient. This is frequently done and usually works but remember that patient who is sedated or under general anesthesia cannot tell you that you are pulling her finger joint out of its socket in an attempt to get her wedding ring off. This actually happened to the sister of one of the editors and her joint pain and dysfunction persisted for several years.
- Always balance the risks and benefits, especially with tattoos. None of us would choose to place a peripheral intravenous line in an arm with a densely colored sleeve tattoo, but this is certainly going to be less risky to the patient than a central line. Similarly, nobody would choose to put an epidural in a patient with a large low back tattoo, but you must balance that against not having an epidural in an obstetrical patient who might really have the need for one to avoid other, much larger, and more real, complications and risks.
- Check the literature regularly for case reports and complications pertaining to tattoos and body jewelry. Again, talk to your colleagues—we are in Portland and face these issues daily.
- As always, use common sense, be respectful, and communicate!

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# We Now Know That Obstructive Sleep Apnea Is More Common Than We Thought—Manage These Patients Carefully and Conservatively

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Obstructive sleep apnea (OSA) is a chronic disease characterized by frequent and recurrent partial or complete upper airway obstruction during sleep. The session of air flow leads to oxygen desaturation, sleep fragmentation, and daytime sleepiness. OSA is associated with wide range of pathophysiologic changes and can be reconsidered as the leading etiology for varieties of diseases; such as cardiovascular abnormalities (hypertension, arrhythmia, and coronary artery disease), stroke, autonomic dysfunction, and metabolic syndrome. OSA is clinically defined as a ≥10-seconds pause in respiration associated with ongoing ventilator efforts. While hypopnea is defined as a moderate reduction in air flow or a >50% reduction in air flow that is associated with a desaturation of >3% from the baseline reading. The average number of apneas and hypopneas/hour of sleep as studied by polysomnography compromises the apnea–hypopnea index (AHI) which can be utilized to score the severity of OSA.

## Epidemiology

The exact incidence of OSA in the adult population is unknown. It was previously thought to be between 5% and 10%, but a recent study showed that one in four US adults appears to be at high risk for OSA. This fact underscores the increased chance of having a patient with undiagnosed OSA as a candidate for general anesthesia.

## Risk Factors

The most clearly recognized risk factor for OSA is a narrow upper airway. The most common etiologies involve congenital abnormalities of the airway (e.g., Pierre–Robin syndrome, midface hypoplasia), hypertrophy of the adenoids and tonsils (especially in children), macroglossia (e.g., Down syndrome), and increased uvula size. Other important risk factors are obesity (body mass index >30 kg/m$^2$), nasal polyps, deviated

nasal septum, and chronic rhinitis. Neck circumference of >17 in for men and >16 in for women also represents an additional risk for OSA. Obesity by itself can lead to OSA or can worsen a pre-existing OSA. In the adult population the male-to-female ratio is 2:1, but this ratio does not apply to children or postmenopausal females. In women over the age of 65 years, the risk for OSA increases threefold. Other predisposing factors for OSA include a family history of OSA, smoking, and use of alcohol, tranquilizers, or sedatives.

## Pathology

The patient with OSA has a smaller and more easily collapsible upper airway. The risk of complete collapse of the airway is accentuated at the end of expiration, when the tissue pressure overcomes intraluminal pressure. The critical collapsible area is usually seen in the velopharynx, as evidenced by imaging studies (computerized tomography, magnetic resonance, or fluoroscopy). Recurrent apnea will lead to intermittent hypoxemia, hypercapnia, and sleep fragmentation, with secondary increase of the sympathetic tone. OSA represents an independent risk factor for cardiovascular morbidity and mortality. A plausible explanation seems to be the increased oxidative stress secondary to alternate hypoxia/reoxygenation. The oxidative stress causes systemic inflammatory response with activation of endothelial cells, leukocytes, and platelets that culminates in early signs of atherosclerosis. OSA is one of the leading causes of systemic hypertension, left ventricular hypertrophy, pulmonary hypertension with right ventricular failure and congestive heart failure, cardiac dysrhythmias, ischemic heart disease, and stroke.

Sleep fragmentation leads to chronic fatigue, excessive daytime somnolence that markedly increases the risk of motor vehicle accidents, memory problems, anxiety, and depression.

## Diagnosis

The diagnosis of OSA is based on patient history, clinical presentation, physical examination, and sleep study (polysomnography). The classical symptoms of OSA are snoring, excessive daytime sleepiness, and witnessed episodes of breathing cessation during sleep. Usually, the patient with OSA is a man, over age 60 years, obese, with a short and thick neck. The “gold standard” for diagnosing OSA remains the polysomnography or sleep study performed overnight in a sleep laboratory. An accurate measurement requires 12 physiologic signals (Table 125.1) with a computer-based automated sleep analysis.

**Table 125.1 ■ Signals Required for Polysomnography (Hypopneic and Apneic Events Are Associated With Arousal From REM Sleep, Oxyhemoglobin Desaturation, Possible Arrhythmias, and High Blood Pressure.)**

| Function | Signal | Response in Obstructive Sleep Apnea |
|---|---|---|
| Sleep | Electroencephalogram (EEG) | Arousal episodes |
| | Electrooculogram (EOG) | Rapid eye movements (REM) |
| | Electromyography submentalis (EMG) | Decrease of chin muscle tone |
| Respiration | Oronasal air flow | Decrease or cessation of air flow |
| | Ribcage and abdominal movement | Increased respiratory effort |
| | Oxygen saturation | Desaturation |
| | End-tidal $CO_2$ | Increased value after apnea |
| Cardiovascular | Electrocardiogram (EKG) | Cyclical variation of bradycardia episode associated to apnea followed by tachycardia<br>Other arrhythmias |
| | Blood pressure | Possible elevated values linking to cardiovascular consequences of OSA |
| Movement | Electromyography tibialis | Limb movement |
| Position | Body position | Correlation with occurrence of OSA |
| Behavior | Video, audio | Snoring, sleep talking, sleep apnea events, movement disorder, seizures |

The final result of the analysis is the AHI, which is the total number of apnea and hypopnea events per hour of total sleep time. According to the AHI, the severity of OSA

can be stratified as shown in Table 125.2.

## Treatment

The mainstay of treatment for OSA is continuous positive airway pressure (CPAP) applied during sleep via a tight nasal or facial mask. Indications for CPAP therapy are an AHI >10 accompanied by symptoms or an AHI >30 regardless of symptoms. This technique has been proven to be efficient in preventing the collapse of the airway and improving breathing during sleep. CPAP therapy improves concentration, alertness, neurocognitive function, and mood. The CPAP has favorable effects on cardiovascular outcome but necessitates a strict commitment from the patient. The addition of humidification, bi-level positive airway pressure (BiPAP), and autotitration of positive airway pressure has been tried to improve compliance and patient comfort. Mandibular repositioning appliances represent a simple and noninvasive alternative method of treatment for mild OSA (AHI 5 to 15) and are used in patients who are unable to tolerate CPAP. The mechanism of action is similar to the jaw-thrust technique. Surgery is reserved for severe OSA or lack of response to CPAP. The main objective of any surgical technique is to enlarge the upper airway. Adenoidectomy, tonsillectomy, nasal polypectomy, septoplasty, uvulopalatopharyngoplasty, maxillomandibular advancement and hyoid expansion are all procedures used to alleviate the symptoms of OSA surgically. If these are unsuccessful and the obstruction is severe, the last option is tracheostomy. As adjuvant therapy, the following may be helpful: losing weight, position therapy, topical application of soft tissue lubricant, and the use of acetazolamide to increase respiratory drive to compensate for the metabolic acidosis caused by hypoxia. Most recently the application of high-flow nasal cannula (HFNC) in the perioperative care of OSA patients is proven to benefit this population during intraoperative moderate or deep intravenous sedation and during postoperative care after general anesthesia. HFNC has shown to be well-tolerated by the patient, easy to use and very useful in preventing hypoxia, and airway obstruction.

**Table 125.2 ■ Apnea–Hypopnea Index (AHI) and Severity of Obstructive Sleep Apnea (OSA)**

| Severity of OSA | Adult AHI | Pediatric AHI |
|---|---|---|
| None | 0–5 | 0 |
| Mild OSA | 6–20 | 1–5 |
| Moderate OSA | 21–40 | 6–10 |

| | | |
|---|---|---|
| Severe OSA | >40 | >10 |

## Outcome

The natural history of sleep apnea is not yet fully described, but the mortality is increased with the development of cardiovascular complications, especially in the middle-aged population. CPAP, surgery, and dieting can improve the outcome and lower the risk of death from cardiovascular complications. We also want to remind our readers that the Anesthesia Closed Claims Project maintains the Obstructive Sleep Apnea (OSA) Death and Near Miss Registry, which was jointly established by the Project and the Society of Anesthesia and Sleep Medicine. Case submission closed on December 31, 2016 and are undergoing analysis to (1) identify the level of monitoring, (2) provide increased understanding as to how and why OSA adverse events occurred, and (3) provide insight regarding how to best construct prospective studies to evaluate and develop best practices for the care of OSA patients.

## Implications for Anesthesia

In October 2005 that was updated in November 2014, the American Society of Anesthesiologists (ASA) developed practice guidelines for perioperative management of patients with OSA. This document should be considered required reading for every anesthesia provider.

## Preoperative Evaluation

Patients with an established diagnosis of OSA with the severity of the OSA graded from the results of the sleep study (AHI) (Table.125.1) should be managed according to certain practice guidelines that are recommended by the ASA. Otherwise, all surgical patients should be evaluated for OSA risk factors. Multiple screening methods are available, such as the Berlin Questionnaire, which has been proven to be specific and sensitive for OSA screening. The Berlin Questionnaire focuses primarily on symptoms of snoring, apnea, fatigue, hypertension, and body mass index (BMI).

The ASA has come up with two models, one for identification and assessment of OSA and a second to be used as a scoring system (Tables 125.3 and 125.4) to predicate the possibility of OSA from the presence of various risk factors. The ASA modules need clinical validation and proof of their usefulness in the perioperative management of OSA.

In patients who are evaluated as being at high risk for OSA and/or who are undergoing a major surgical procedure with a possible requirement for high doses of opioids for postoperative pain, it is advisable to postpone an elective surgery until

further evaluation and proper management of their OSA can be undertaken.

During the preoperative evaluation of surgical patients with OSA, it is vital to perform a comprehensive history and physical examination to learn of any comorbidities or previous anesthesia-related complications and to document the settings of the patient's CPAP/BiPAP. One should also make sure that the patient's equipment will be available for postoperative use.

The use of sedatives and analgesics should be avoided in the preoperative setting because of the increased sensitivity to any respiratory depression. The consequences of upper airway muscle tone relaxation could lead to devastating effects before the start of surgery and anesthesia. It is important not to underestimate the challenge of mask ventilation and/or intubation in these patients and to remember to have a clear plan for airway management before going ahead with a general anesthetic.

**Table 125.3 ■ ASA-Proposed Example for Identification and Assessment of OSA**

| Clinical signs and symptoms suggesting the possibility of OSA | |
|---|---|
| 1. Predisposing physical characteristics | BMI >35 kg/m$^2$ (95th percentile for age and gender) |
| | Neck circumference >17 in or >43 cm (men); >16 in or >41 cm (women) |
| | Craniofacial abnormalities affecting the airway |
| | Anatomical nasal obstruction |
| | Tonsils touching or nearly touching in the midline |
| 2. History of apparent airway obstruction during sleep | Snoring (loud enough to be heard through closed door) |
| | Frequent snoring |
| | Observed pauses in breathing during sleep |
| | Awakens from sleep with choking sensation |
| | Frequent arousals from sleep |
| | Intermittent vocalization during sleep |
| | Parental report of restless sleep, difficult breathing, or struggling respiratory efforts during sleep |
| 3. Somnolence | Frequent somnolence or fatigue despite adequate "sleep" |
| | Falls asleep easily in a nonstimulating environment |
| | Parent or teacher comments that the child appears sleepy during the day, is easily distracted, overly |

| | |
|---|---|
| | aggressive, or has difficulty concentrating |
| | Child often difficult to arouse at usual awaking time |
| If patient has signs or symptoms in two or more of the above categories, there is a significant probability that OSA is present. | |
| Sleep study done | |

| Severity of OSAw | Adult AHI | Pediatric AHI |
|---|---|---|
| None | 0–5 | 0 |
| Mild OSA | 6–20 | 1–5 |
| Moderate OSA | 21–40 | 6–10 |
| Severe OSA | >40 | >10 |

AHI, apnea–hypopnea index; ASA, American Society of Anesthesiologists; BMI, body mass index; OSA, obstructive sleep apnea.

## Intraoperative Management

OSA patients should be considered potential difficult airway management patients, and the anesthesia team should be prepared in advance for this possibility.

As a general rule, whenever it is possible, a regional anesthesia technique should be used instead of general anesthesia. General anesthesia with a secured airway is a better choice than monitored anesthesia care (MAC) with spontaneous breathing and an unsecured airway. Short-acting anesthetic drugs represent an attractive choice for general anesthesia.

For monitoring, standard noninvasive monitoring such as pulse oximeter, capnography, electrocardiography (EKG), and blood pressure are critical, especially for patients who are breathing spontaneously under MAC.

**Table 125.4 ■ ASA-Proposed Example for OSA Scoring System**

| | | | |
|---|---|---|---|
| Severity of sleep apnea based on sleep study or clinical indicators if sleep study not available; point score (0–3) | | None<br>Mild<br>Moderate<br>Severe | 0<br>1<br>2<br>3 |
| Invasiveness of | Superficial surgery under | | 0 |

| | | |
|---|---|---|
| surgery and anesthesia; point score (0–3) | local or peripheral nerve block anesthesia without sedation | |
| | Superficial surgery with moderate sedation or general anesthesia | 1 |
| | Peripheral surgery with spinal/ epidural anesthesia (no more than moderate sedation) | 1 |
| | Peripheral surgery with general anesthesia | 2 |
| | Airway surgery with moderate sedation | 2 |
| | Major surgery with general anesthesia | 3 |
| | Airway surgery with general anesthesia | 3 |
| Requirement for postoperative opioids; point score (0–3) | None | 0 |
| | Low-dose oral opioids | 1 |
| | High-dose oral opioids, parenteral or neuraxial opioids | 3 |
| Estimation of perioperative risk: overall score = score from A plus the greater of the score for either B or C; point score (0–6). Patients with score of 4 may be at increased perioperative risk from OSA; patients with a score of 5 or 6 may be at significantly increased perioperative risk from OSA. | | |

ASA, American Society of Anesthesiologists; OSA, obstructive sleep apnea.



Extubation should be done in the semiupright position when the patient is fully awake and completely recovered after muscular blockade.

## Postoperative Care

The main objectives in postoperative care are oxygenation and maintenance of a patent airway using supplemental oxygen and CPAP/BiPAP support. This is especially true for patients who are already on these treatments or high-risk patients.

Adequate analgesia with minimal depression of respiratory drive provided by continuous analgesia through regional techniques such as continuous nerve blocks, paravertebral blocks, or epidurals are the best choice for postoperative pain control. When appropriate, regional techniques should be used, preferably without opioids. Nonsteroidal anti-inflammatory drugs or other adjuvants should be used whenever possible to decrease opioid requirements. The use of patient-controlled analgesia (PCA) without the continuous infusion mode represents a better alternative than opioids administered on a regular or as-required basis. The antidote for opioid overdose should be readily available to rescue the OSA patient with respiratory compromise. Supine position should be avoided, and lateral, prone, or sitting position should be used.

Continuous monitoring of oxygenation, breathing, blood pressure, and heart rhythm are required because of the possibility of serious complications such as hypertension, dysrhythmias, hypoxia, and airway obstruction, the latter potentially requiring urgent reintubation. Studies have shown a 2 to 3× increase in all-cause mortality in patients with OSA, as well as a 2 to 3× increase in perioperative cardiopulmonary complications. The use of CPAP has only been studied in retrospective reviews, as there are ethical questions regarding holding someone's home medical therapy, and they have achieved mixed results. In some studies it decreased the risk of mortality by ~1/3rd but was not statistically significant in others. One study administered CPAP to patients after abdominal surgery without a high likelihood of OSA and it reduced postoperative cardiopulmonary complications. Studies have also shown that abrupt CPAP withdrawal increases blood pressure by an average of 10 mm Hg, but does not alter endothelial function to cause a significant change in myocardial or renal perfusion.

## Discharge Criteria

In addition to the standard discharge criteria used routinely in the postanesthesia care unit (PACU), patients with OSA should be able to maintain adequate oxygenation on room air with no hypoxemia or critical airway obstruction when they are asleep. OSA patients should stay at least 3 hours longer than non-OSA patients to ensure the required discharge criteria. OSA patients who develop an episode of hypoxemia or critical airway obstruction while in the PACU require an extended monitoring period of 7 hours (median time recommended by ASA guidelines in this circumstance) and the most careful evaluation thereafter (many anesthesia providers simply secure a postoperative bed in this instance). Patients with mild OSA who have undergone minor surgery

(superficial plastic surgery, eye procedures, and superficial orthopedics) under local or regional anesthesia can be discharged home on the same day. Patients with moderate OSA and intermediate comorbidities who have undergone intermediate-risk surgery (does not include abdominal, faciomaxillary, thoracic, or intracranial) should be hospitalized in a standard surgical unit. Patients with severe OSA, necessitating CPAP at home and/or who have had major surgical procedures, should be admitted to a step-down unit or intensive care unit until the threat of respiratory complications is no longer present. Continuing CPAP in patients with severe OSA was associated with reduced perioperative complications in some series but not in others.

## Outpatient Surgery

Outpatient surgery for OSA patients remains controversial. According to Sabers et al., the presence of OSA does not increase the risk of readmission to the hospital after ambulatory surgery. However, this view is not shared by many same-day surgery anesthesia providers, and it is the practice in some ambulatory surgery centers to refuse care to sleep apnea patients (and sometimes even suspected sleep apnea patients). Risk must be assessed for each individual patient, because there are a large number of undiagnosed cases of OSA (Table 125.5).

## OSA Characteristics for Children

The peak period for OSA in the pediatric population is preschool age, with equal boy/girl distribution. The common causes are adenotonsillar hypertrophy, obesity, and craniofacial anomalies. Usually, children with OSA suffer growth retardation, hyperactivity disorders, developmental delay, or attention deficit disorders. Excessive daytime somnolence is uncommon in children with OSA. Sleep studies show normal sleep architecture and a <50% cortical arousal with apnea, but results should be interpreted according to the age of the child (Table 125.1). The treatment is primarily surgical (adenotonsillectomy), and CPAP is used as required.

Anesthetic management of children with OSA should not include premedication with sedatives and respiratory depressant medication, and a difficult airway should always be anticipated. Induction of general anesthesia is achieved by inhalational agents. The application of an artificial oral airway and CPAP will improve airway patency and mask ventilation. Administration of antisialagogue (anticholinergic) medications can be beneficial during both the intraoperative and postoperative periods. Neuromuscular blockade should either be avoided or full recovery from its effects ensured before extubation. Doses of opioids should be decreased, and it is preferable to use short-acting, noncumulative agents. The incidence of airway obstruction in the immediate postoperative period is higher in children with OSA, especially in those who undergo

adenotonsillectomy. Because of the increased risk for postobstructive negative-pressure pulmonary edema that necessitates reintubation and mechanical ventilation, children with moderate to severe OSA should always be hospitalized overnight after surgery.

**Table 125.5 ■ Consultant Opinions Regarding Procedures That May be Performed Safely on an Outpatient Basis for Patients at Increased Perioperative Risk for Obstructive Sleep Apnea**

| Type of Surgery/Anesthesia | Consultant Opinion |
|---|---|
| Superficial surgery/local or regional anesthesia | Agree |
| Superficial surgery/general anesthesia | Equivocal |
| Airway surgery (e.g., Uvulopalatopharyngoplasty [UPPP]) | Disagree |
| Tonsillectomy in children <3 years old | Disagree |
| Tonsillectomy in children >3 years old | Equivocal |
| Minor orthopedic surgery/local or regional anesthesia | Agree |
| Minor orthopedic surgery/general anesthesia | Equivocal |
| Gynecologic laparoscopy | Equivocal |
| Laparoscopic surgery, abdominal surgery | Disagree |
| Lithotripsy | Agree |

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## TAKE HOME POINTS

- Snoring, excessive daytime somnolence, and witnessed apnea episodes together with an AHI >5 are positive for OSA diagnosis.
- In the absence of sleep study, have a high index of suspicion to the diagnosis of OSA in the presence of risk factors.
- Avoid preoperative benzodiazepines or opioids.
- Use regional anesthesia whenever appropriate or general anesthesia with secured

airway (an endotracheal tube or, controversially, a laryngeal mask airway).
- Extubate in semiupright position, when the patient is awake and fully recovered from neuromuscular blockade.
- Use supplemental oxygen with or without CPAP and monitor oxygen saturation.
- Avoid the supine position.
- Use adjuncts to decrease opioid requirement.
- Discharge adult patients when they reach their baseline room air oxygen saturation and have no hypoxemia or critical airway obstruction when not stimulated.
- Pediatric patients with moderate to severe OSA should be hospitalized overnight after surgery.

## Suggested Readings


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# Don’t be Shy About Borrowing ICU Equipment, Medications, and Personnel for the Critically Ill Patient Going to the Operating Room

Elliott Karren, MD and Matthew Griffee, MD

A 46-year-old male refinery worker suffers an explosive burn injury to his trunk. Over the initial week of hospitalization in the burn ICU, he develops acute lung injury and requires venovenous extracorporeal membrane oxygenation to treat refractory hypoxemia. The ventilator mode is airway pressure release ventilation. His respiratory failure, volume overloaded state, and lung contusions lead to pulmonary hypertension, treated with inhaled nitric oxide. Cardiac output and pulmonary artery pressure are monitored with a pulmonary artery thermodilution catheter. Your burn trauma surgical colleague schedules OR time for debridement of eschar. The anesthesia technician assisting you with transport asks, “What equipment do you need in the OR for this case?”

Anesthesiologists spend substantial time managing stable patients undergoing elective surgical procedures. However, we are also asked to manage critically ill patients in the OR. Certain aspects of critical care are routine for anesthesiologists, for example, ventilator management and titration of vasoactive medications. Other aspects of care for the ICU patient may be less familiar. The aim of this chapter is to highlight some medications, devices, and personnel used in the ICU that may be useful for the intraoperative care of critically ill and injured patients.

## Pulmonary Arterial Vasodilators

Inhaled nitric oxide, epoprostenol, and iloprost are some medications used to manage pulmonary hypertension and right heart failure after cardiothoracic surgery or in patients with severe acute lung injury. Inhaled nitric oxide (iNO) is given as a continuous inhalational agent, while epoprostenol can be given either parentally, via a central line, or as a continuous nebulized solution. Iloprost is unique in that it is given intermittently

via nebulizer. Inhaled nitric oxide is started at a dose of 40 ppm, titrated down rapidly to 20 ppm, and then more gradually as oxygenation and ventilation improve, until a dose of 5 ppm is reached. It is then slowly weaned in increments of 1 ppm until discontinuation. Epoprostenol is initiated at 25 to 50 ng/kg/min by continuous inhalation. As with iNO, epoprostenol is weaned in half-dose increments, but without the need for as slow a taper at the end.

It is important that these medications are continued intraoperatively, since abrupt discontinuation of any of these medications can be associated with a number of side effects, including hypoxia (due to decreased ventilation–perfusion matching) and rebound pulmonary hypertension. For the same reasons, rapid intraoperative titration should be performed with caution.

Because the epoprostenol and nitric oxide delivery systems must travel with the patient between the OR and ICU, the simplest solution may be to travel with the ICU ventilator as well. The iloprost atomizer, by contrast, can be connected to the anesthesia circuit, but it requires a different adapter than the interface used for albuterol. Alternatively, inhaled iloprost therapy can be scheduled for a time just prior to any patient transport, negating the need for delivering it during imaging or procedures outside the ICU.

Beware of serious potential adverse effects! Nitric oxide can cause methemoglobinemia. Both administration of nitric oxide and prostaglandins have been associated with pulmonary edema in the setting of LV systolic dysfunction, due to improved right-sided cardiac output. Epoprostenol has been associated with thrombocytopenia. All three inhaled agents are known to inhibit platelet aggregation. Due to mucosal vasodilatation, any inhaled vasodilator can cause bronchoconstriction and systemic vasodilation can occur at higher doses of inhaled vasodilator therapy.

## Antibiotics and Immunosuppressive Agents

Critically ill patients with sepsis require a regimen of antibiotics. Antibiotics require constant plasma concentrations above the bactericidal or bacteriostatic threshold in order to be efficacious. Drops in plasma concentration due to missed doses can lead to bacterial resistance or ineffective resolution of infection. Remember to check with the ICU staff to see if the patient is due for important medications before starting the case. The same consideration applies to immunosuppression medications for organ transplant recipients.

## Temporary Pacemakers

During cardiac surgery, temporary pacemaker leads are attached to the epicardium. Temporary pacemaking may be indicated if severe bradycardia is discovered during

weaning from bypass or if damage to the conducting system occurs during surgical intervention. Epicardial pacing wires are for temporary use (hours to a few days). Patients with epicardial leads who have effective endogenous pacing still remain at risk for bradycardia or high-degree heart block if they require multiple trips to the operating room. Prior to taking a patient with epicardial pacing leads to the OR, be sure to determine why the leads are in place, and whether the patient is pacemaker dependent. You want to make sure that you know the settings of the temporary pacemaker, as well as the rate and rhythm of the endogenous conduction system.

## ICU Ventilator

ICU ventilators almost exclusively employ piston-based designs for mechanical ventilation. Piston-based designs have the advantage of delivering more accurate tidal volumes, which may be challenging in bellows-driven ventilators (commonly used in the OR) in patients with reduced lung compliance, such as in acute lung injury or pulmonary edema. Additionally, older generation OR ventilators may not be able to generate sufficient minute ventilation to prevent severe hypercarbia and respiratory acidosis. When you are planning an anesthetic for a patient with stiff lungs, don't forget the option of taking the ICU ventilator to the OR, because stiff lung areas can easily become atelectatic, leading to an increase in shunt and hypoxemia.

It is important to take note of the ICU ventilator settings when transitioning to the anesthesia machine ventilator. The standard-of-care for critically ill patients with respiratory failure is to use physiologic tidal volume settings (6 to 8 mL/kg predicted body weight) and higher PEEP settings. Clinical trials demonstrate that patients with lung injury benefit from lower tidal volumes. Clinical trials have also shown that patients undergoing thoracic surgery and major intra-abdominal surgery benefit from lung protective ventilation. Thus, careful consideration of the risks and benefits of limiting plateau pressure and tidal volume are warranted when caring for ICU patients who require perioperative mechanical ventilation.

Patients with the most severe lung injury may require rescue ventilator modes such as airway pressure release ventilation, high-frequency oscillatory ventilation, or venovenous extracorporeal membrane oxygenation—collectively termed rescue strategies—that are not available on the anesthesia ventilator. In such cases, ask yourself whether surgery should be delayed until the lung injury improves and the ventilator setting is changed to a conventional mode, or whether surgery should be done in the ICU. In rare cases, a ventilator capable of these advanced ventilator modes or the ECMO circuit will need to be transported to the OR.

Airway pressure release ventilation maintains a high time-averaged mean airway pressure to avoid de-recruitment, while still allowing a patient to have spontaneous

ventilation. Take note that patients with a lot of dead space ventilation may be getting a substantial amount of alveolar ventilation with spontaneous breaths during the P high phase of breathing. Be vigilant to see if the patient is taking breaths at P high and what the total minute ventilation is on the ICU ventilator. If the patient requires a paralytic, the loss of spontaneous ventilation may cause a substantial decrease in minute ventilation. It may be necessary to increase tidal volume or respiratory rate to maintain acceptable $CO_2$ levels during anesthesia.

## ICU Personnel

### Respiratory Therapist

It is challenging to transport and care for patients who require rescue ventilator modes or inhaled pulmonary vasodilators. While some providers may be familiar with these therapies, the additional equipment makes transport and intraoperative care more complex. In these cases, having a respiratory therapist during transport and potentially for some of the time during the case may be helpful. Respiratory therapists are well trained in the practical aspects of administering airway medications, and changing ventilator settings on ICU ventilators. Having them available allows you to focus more attention on resuscitation of a critically ill patient and less attention on the ICU ventilator alarms and buttons.

### Ventricular Assist Device Coordinator

We have all noticed increasing numbers of patients obtaining ventricular assist devices (VADs) for heart failure. Given this growth, all anesthesia providers should be familiar with practical anesthesia implications of VADs. Because there are several VAD manufacturers, adjustment and troubleshooting of VAD parameters is complex. Mechanical heart support hospitals have VAD coordinators who are on call to ensure patients with temporary or permanent VAD support can be transported safely. A VAD coordinator may be indispensable in the OR if the VAD needs to be adjusted at a time when the other people in the room have to focus attention on resuscitation and surgery. Keep in mind that a patient dependent on a VAD for most of the cardiac output may have little or no pulse pressure, resulting in inaccurate readings of automated blood pressure cuffs and poor waveforms of a pulse oximeter. The recommended technique for taking noninvasive blood pressure in this circumstance is to use a vascular Doppler probe and a manual BP cuff. The first flow detected in the brachial artery with releasing the cuff is the mean arterial pressure.

## Lung De-recruitment

If the ETT gets disconnected in transitioning from the ICU vent to the transport breathing circuit and the patient has been needing PEEP to maintain adequate oxygenation (due to stiff lungs), you may need to do a recruitment maneuver when getting into the OR or upon return to the ICU. One way to do a recruitment maneuver is to use manual ventilation and keep airway pressure 40 cm water for 40 seconds. On a ventilator, the tidal volume and PEEP can be increased for a few minutes, then slowly decreased to maintenance settings.

## TAKE HOME POINTS

- Anesthesiologists can profoundly impact the care of the critically ill patient. Patients get the best care when there is a seamless articulation of ICU and OR care. So pay very careful attention to key details of the ICU care plan in order positively affect the clinical outcome in ways that may not be manifest immediately in the OR.
- Spending a little extra time getting a complete sign out from the ICU nurse and intensivist, and making sure that the ICU equipment, medications, and personnel the patient needs are available for intraoperative care may prevent serious problems during a challenging case.

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# The Dao of Positioning

Raymond G. Graber, MD, Selina Read, MD, and Catherine Marcucci, MD

## The Problem

First, let's start off this topic with a bit of wishful thinking—wouldn't it be nice if surgery could always be performed on a patient in a neutral or "natural" position? Alas, sometimes the surgeon desires variations or even extremes of positioning that diverge from what is safest for the patient. Although the entire operative team is responsible for positioning of the patient, the practical and even legal truth is that the anesthesia team is "most responsible." After all, we are the ones who have caused the lack of consciousness and insensate condition that prevents the patient from recognizing trouble and correcting it by literally moving out of harm's way.

Included in this overall "positioning" responsibility is the necessity to take into account the patient's anatomy and physical vulnerabilities, baseline physiology and comorbidities, and the perturbations that occur with positioning and surgical manipulations. You also need to understand the proper use of a wide variety of positioning devices and equipment.

**On an existential level, why is your job as a "positioner" so crucial? Basically, because we are in the business of preventing pain!** Remember always that both acute and chronic positioning injuries can be extremely painful. We tend to think about the acute issues such as soft tissue damage, corneal abrasions, vascular compression, and nerve compression or stretch, but don't forget that there can be long-term problems such as chronic pain, neuropathy, nerve regeneration pain, and the **ever-dreaded** and devastating complication—visual loss. We have found that positioning injuries to the face, arms and hands, and genitals are especially difficult and painful complications for patients, and hence us.

Positioning injuries are also painful for legal and financial reasons. The American Society of Anesthesiologists sponsors the Closed Claims Project—a database of adverse anesthetic outcomes obtained from the closed malpractice claims files of liability insurance companies. A 1999 review of this data revealed a significant number

of claims that asserted perioperative peripheral nerve injury. The most common nerve involved was the ulnar nerve (4.5% of all claims in the project). Some of these injuries may have been secondary to brachial plexus block, but 85% occurred on patients who received general anesthesia. The next most common nerve injury was to the brachial plexus (3.3% of all claims) of which about 75% occurred in patients who were under general anesthesia. Claims also involved sciatic/peroneal, median, radial, and femoral nerves. There are also other position-related injuries in the database—including vision loss, and neurologic injury after shoulder surgery performed in the sitting position.

## The Lessons

We were fortunate to have received some superb instruction on patient positioning early in our training, and these lessons in the "philosophy of positioning" have stayed with us down through the years. Here are some recommendations on how you should think about and approach patient positioning.

(a) **First principles:** Remember that there are both **primary** and **secondary positioning complications.** Primary positioning injuries involve actual tissue damage from torquing, twisting, gravity, pressure injuries, pinch points, and improper use of positioning equipment. Secondary positioning complications result from the physiologic consequences of an unnatural and prolonged position or turning, such as prolonged beach chair position with its deleterious effects on cerebral perfusion. We must be ever vigilant in every case to prevent positioning injuries.

(b) Let's talk **terminology:** There are different components to positioning. "Moving" is easiest—generally it's the process of sliding the patient from one bed to another by either lifting sheets or using a rolling device. A supine-to-supine move, in a pure lateral direction. Then there is "turning"—the process by which a patient gets moved from the supine to a lateral or prone position (or back to supine at the end of the case). A turn-to-prone generally involves turning off a cart and on to a special frame or chest rolls placed on the OR table. There is a variety of bed maneuvers that can happen next —such as flexing, extending, tilting, etc. Lastly, there is "rotation"—which is turning the whole bed on its axis so that now it's not the head that is nearest to the anesthesia machine, but the side of the patient or even the feet. With each of these maneuvers, there is potential for patient injury or dislodgment of airways and vascular access.

(c) **Checking:** Each time one of these maneuvers is completed, the patient's position should be checked. What does that actually mean? Well, the head and neck and spine should be in alignment and neutral. Arms should not be abducted so high as to risk brachial plexus stretch injury. Breasts and genitals should not be trapped or pinched. Potential pressure points should be padded. Axillae should be free from compression.

(d) **Preparing to turn:** Turning is the most complicated component of positioning, and proper preparation makes a big difference. Tape your lines (both venous and arterial) such that you do not make loose "purse handles" or loops that can easily be caught when you flip a patient. Place your leads and pads such that a minimum of replacement is required after you turn. Have adequate staff available to do the turn—at minimum one on each side, one at the foot of the bed, and a member of the anesthesia team at the head of the bed. We take responsibility for managing the head and neck and airway during the turn. It's helpful to have one additional person to watch the arms and lines during the turn. Disconnect most monitors prior to the turn. We generally like to disconnect the anesthesia circuit from the airway immediately prior to turning, to decrease the risk of pulling the airway out.

(e) **Turning:** There are many individual styles of turning or flipping a patient and they all work if they are done carefully and consistently. We were taught to envision the patient as occupying an envelope in space (a burrito-shaped package, if you will) and try to turn everything as a unit. When turning from supine to prone, lines and monitors on the arm closest to the bed serve as an axis which the body can be rotated around. The person handling the head and neck calls the turn. The head and neck should be kept in alignment with the spine. Arms and legs are controlled so that nothing gets torqued or twisted or dropped. **Gravity is not our friend here.** Once the turn is completed, the airway is hooked up, tube position is rechecked, and the rest of the monitors are reattached. If a monitoring pad gets dislodged, do not try to reuse it or restick it—just get a new one.

(f) **Airway issues:** Of course, the most important "line" is the oxygen line, i.e., the airway device or endotracheal tube. After an airway is placed, you have to secure it in a way that it won't be lost with changes in position. You can imagine the scenario where the patient is prone, drooling up a storm, tape adhesive is dissolving, the circuit is under tension, and the tube starts working its way out. There are many tricks to deal with this. You can give 0.2-mg glycopyrrolate IV to any patient who is going to be prone, to reduce the drools. You can use benzoin or Mastisol® to better secure tape. Some practitioners will put sterile transparent IV dressings over the tape to keep it dry. You can also double cover and secure with both tape and a tube tie. The good thing about a tie is that it won't loosen up and fall off, but you can't leave a tie in place when the neck is going to be prepped out. Next, after you have turned the patient, hooked the circuit back up, and verified breath sounds, make sure the circuit is supported or secured so that there is no weight pulling on the tube. Make sure that the airway circuit is long enough to tolerate any changes of the position of OR table within the room. Make sure the endotracheal tube and airway circuit are as accessible as possible for suctioning and checking.

Alright, now let's talk about some **airway rescue scenarios**. You should know, **before it happens,** what you are going to do if the patient is accidentally extubated during a turn. The best approach is to quickly turn back supine and resecure the airway. What about the situation where the case is underway and the patient gets extubated in the prone position? You won't be able to immediately turn the patient—the surgeon will have to do something to cover the incision, and a bed has to be brought in to the OR to flip on to. Yes, there are stories about legendary anesthesiologists who have rushed into rooms when prone patients in pins were extubated and reintubated patients from the floor underneath the patient—and in the famous case at Hopkins, it's actually true—but you don't want to have to rely on being a legend. An easier alternative is to place an LMA if you need to attempt to oxygenate and ventilate prior to the turn.

(g) **Equipment issues:** You must really understand how to use positioning equipment, including frames, sleds, arm boards, arm rests, and the OR table itself. Positioning complications can occur easily as a result of the patient–equipment interface—for example, pressure points and stretch injuries. A classic example is peroneal nerve palsy secondary to compression from stirrups. On another note, remember to adjust the height of transducers when you turn or position a patient, in order to maintain accurate readings. Also, check all equipment when you have raised or lowered a patient vertically. We once saw a case where a patient was raised vertically and his hand became trapped under a Mayo stand, which resulted in skin necrosis to his thumb and forefinger—not a happy day for anybody in the room.

(h) **Bean bags**: These ubiquitous "patient positioning devices" are frequently used for positioning in the operating room, and are most commonly used for securing patients in the lateral position for orthopedic, thoracic, and urologic procedures. How are they used? The patient starts out supine on the bean bag, and is then turned to the lateral position. The flexible bean bag is molded around the patient, suction is attached to the device, and the bean bag now becomes a rigid structure. Sometimes, surgeons will want to flex the bed as part of their positioning plan—this is common for thoracic surgery. This bed maneuver should be done prior to placing the bag on suction. At the end of surgery, the bean bag suction is removed, and it will become flexible again. There are a few things to watch out for. The bean bag should not be positioned so high that it is compressing the axilla. An axillary roll is commonly used, but may not always be necessary if the bean bag has adequately raised the chest wall off the bed. Also, remember that there is potential for pressure points that can result in injury. Injury to the dependent lateral femoral cutaneous nerve (meralgia paresthetica) has been reported in hip replacement surgery (secondary to compression at the anterior superior iliac spine). We have also seen a dependent radial nerve injury due to the

beanbag compressing the nerve against the posterior lateral aspect of the humerus.

(i) **The Survey:** The absolute best thing we were ever taught was to stand back after a patient is positioned but before surgical prep commences and make a quick visual head-to-toe survey from all sides of the patient. Does the patient **look** comfortable and as "neutral" as possible? Could you imagine yourself in such a position for the duration of surgery? Remember to consider both the degree of deviation from neutral anatomical position and the length of time the patient will be mobilized. If any changes need to be made, this is the time to do it. Use your best social skills with your surgeon to accomplish your goals. Also make sure that all limbs are well-secured, and not at risk of falling from their designated spots. Once the drapes go up, it is much harder to deal with these issues.

(j) **Rotations:** Surgeons will frequently request rotation of the OR table. A 90-degree rotation is frequently used—this allows the anesthesia team to have good access to one side of the body and to not be too far away from the head. Some surgeons request a 180-degree rotation of the OR table so that they have unrestricted access to the head and neck. This can be problematic for us, because now you only have access to the bottom of the feet. Work with your surgeons to see if they can tolerate a 165- to 170-degree rotation instead. Try to preserve access to one arm and one leg—this allows you to put in extra peripheral IVs, an arterial line, or even femoral lines if you need to without totally displacing and disrupting the surgeon. You do not want to have your only working IV located in the arm or hand that is away from you or is tucked.

(k) **Lines:** When planning where you are going to place intravenous and arterial access, try to keep in mind what limb you will have easiest access to once the patient is in their final position. If at all possible, it pays to have your arterial line and best IV access in the limb you have access to. It is also not a bad idea to place a spare IV before positioning. It can be capped for the turn, but be available later in the case if needed.

(l) **Extremes:** The very thin patient may be more prone to pressure point injuries, and need more padding—because they have less built in cushioning. The obese patient may require special OR tables which are rated for heavier patients. You will need more help to position these patients safely. (And by safely—I mean for the patient and for the staff!) It may be worth discussing with the surgeon whether that planned prone case could be done in the lateral position instead. The obese patient also requires extra padding because of the extra weight. Brachial plexus injuries have been reported in obese patients who have been placed in prolonged Trendelenburg position where shoulder braces were being used to prevent the patient from sliding down the OR table. These injuries have also been seen in the obese patient in the supine

position when there was inadequate padding behind the arms, and this may be further potentiated by being in the reverse Trendelenburg position. The elderly patients may also be more prone to pressure point injury, and need good padding. We have seen elderly with tissue paper skin get tears in their skin with turning and moving. (In some cases, we have wrapped the arms with protective cotton roll or gauze prior to a move.) Also watch out for arthritic necks and shoulders, which do not have the same range of motion that they once had. You can check range of motion during your preop exam, and simulate the position that they will be in during surgery to see if it is tolerable.

(m) **Documentation:** The patient's position must be checked and documented throughout the case. This certainly includes documenting the steps that were taken to avoid any and all of the recognized positioning complications at the time of the initial turn or positioning. This cannot be stressed strongly enough. There are positioning complications that arise from the anatomic and physiologic sequelae that occur in certain positions, even if every precaution is taken. You can do "everything right" and still have a complication. Thorough documentation may prevent these situations from becoming malpractice situations. We were also taught that the patient should be surveyed every 15 minutes as much as possible and a note made in the anesthesia record.

## TAKE HOME POINTS

- Assume that you have the primary responsibility for safe positioning and minimizing the risks of positioning complications and injuries.
- Positioning injuries and complications can be very painful and difficult for the patient to deal with. You have to give these clinical issues your utmost attention.
- Plan for the turn and/or position from the time you bring the patient into the OR. This includes planning the placement of monitors, lines, and leads. Consider redundant intravenous access when it can be accomplished quickly and with little risk to the patient. You might need it only once in a while, but if you do need it, you won't be sorry you have it.
- When turning a patient, imagine that he is a neatly packaged bundle and turn the whole bundle as a unit. Pay special attention to whatever crosses the boundaries of the bundle. You must prevent equipment elements and body parts from being dragged, torqued, or hyperextended in a turn or repositioning maneuver.
- Somebody, as in a specifically designated anesthesia person, has to assume primary responsibility for the head, neck, and airway. It starts with proper securing, then disconnecting, safely turning, and reconnecting the airway. This includes establishing that the ETT remains where you want it after the turn.

- Take a moment to carefully survey the patient in the final "turned" or positioned patient before the surgical prep begins.
- If the OR table is to be rotated to facilitate the surgeon's access to the operative site, negotiate for a few degrees in order to preserve your access to a hand, arm, arm board, and leg. The closer to 90 degrees, the better.
- Use special care when dealing with patients with extremes of weight and age.
- Document the initial positioning safety checks and ongoing intraoperative positioning checks as possible!

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# The Supine Position—Complications Can Still Arise!

Kristin Bowden, CRNA DNAP MBA and Richard Botney, MD

The operating room schedule reads "supine position." At first, most anesthesia providers would be pleased to see this neutral–recumbent position listed. Almost all anesthetics are initiated with the patient in the supine position. If the patient remains in this position after induction, efforts and risks associated with repositioning are minimal. No manipulation of limbs means no overstretching or pulling of extremities, and no strategic placement of excessive bulky padding in places where ischemia can manifest due to excessive pressure. Accessing intravenous lines and placing invasive monitors can be accomplished with ease. Most importantly, the airway is readily accessible. The supine position produces minimal strain and stress on the body and its systems, and although the type of operation ultimately determines the patient position, presumably, the supine position is optimal for many surgical procedures.

Nonetheless, there are complications related to the supine position! And it is very important that the anesthesia provider be aware of these. In some cases, the risk arises because of specific patient conditions, as we highlight in our chapters on patients with spastic conditions or who have undergone amputations. For most cases, however, the risk results from interactions between patient physiology and the specific effects of positioning, creating difficulties in achieving optimal anesthetic management, for example ventilatory challenges in the morbidly obese individual. Alternatively, there are specific complications that can result in patient morbidity and adverse outcomes, such as nerve or ocular injuries. The anesthesia provider should employ various strategies to minimize these risks.

## General Considerations for Patient Positioning

It is important when situating patients that they should never be placed into a position they would not or could not assume when awake. For example, a patient with limitations in range of motion (ROM) of the upper extremity due to arthritis should not have their limb placed in a position outside their normal ROM. Discussion about ROM limitations

due to pain, fractured bones, arthritis, or other conditions that can result in mechanical limitations to ROM should be clarified with patients during the preoperative evaluation.

The anesthetic plan should involve all members of the operating room (OR) team, with **shared responsibility** for the movement and positioning of the patient. This includes the patient, as after a patient is transferred to the OR table, they can participate in positioning themselves prior to the induction of anesthesia. In so doing, they can verbalize their own comfort. This will help reduce the risk of positioning-related complications and increase the likelihood of an injury-free outcome.

Once the patient has been anesthetized, pressure points should be properly padded and the neck, spine, and other joints should remain in a neutral position. Limb positions should not be stretched beyond acceptable limits, and limbs should be well secured to ensure they do not fall off the table during surgery. A pillow placed under the knees can reduce lumbar strain and the possibility of the patient experiencing back pain, especially in patients with pre-existing back discomfort. If this is done before induction, the patient can provide feedback about how well the pillow reduces back pain. If steep Trendelenburg, reverse Trendelenburg, or tilting the table side to side is to be used during the surgical procedure, a preassessment should be done to ensure the patient is completely secured and will not slide during the procedure.

The following checklist is a useful tool for evaluating the correct position (including the supine position!) and safety of a patient when an anesthetic is being administered.

## Positioning Checklist

) **Airway.** No alteration of ETT patency or placement (including depth). Recheck capnograph for waveform tracing formation.
) **IV lines and invasive monitors.** Check patency of IVs and flow of IV fluid, and arterial tracing should not be dampened (e.g., if arms are tucked).
) **Eyes.** Closed and protected. Do **NOT** rush this step.
) **Neurovascular.** Vulnerable areas padded and excessive extension/abduction avoided.
) **Cables, catheters, and electrodes.** Should not be pressed into skin (e.g., from being underneath patient or passing over the face).
) **Access.** At-risk areas should remain accessible for review, if possible.

## Complications Related to Physiologic Changes

The supine position is associated with a number of physiologic changes that can influence anesthetic management, making it more complicated and resulting in the possibility of undesirable outcomes. Changes of particular interest may occur to the respiratory and cardiovascular systems.

## Respiratory

In the supine position, the intra-abdominal contents and diaphragm shift cephalad and compress the adjacent lung tissue. Functional residual capacity (FRC) decreases with a change from the upright to the supine position. This is exacerbated in anesthetized patients, even more so when the patient is obese. Small airways begin to collapse, resulting in a decline in closing capacity. Healthy, spontaneously breathing patients have a normal tidal volume that is typically above closing capacity, and their small airways remain open for gas exchange. This function changes as the body grows older: By age 45, normal tidal breathing causes some airway collapse in the supine position, and by age 65, collapse happens in the upright position. As the FRC decreases there is potential for the closing capacity to exceed the FRC, which can lead to ventilation–perfusion (V/Q) mismatch and subsequent hypoxemia. Demographics at risk for this include the elderly, who have higher closing capacities, and obese or pregnant patients who already have a reduced FRC. The effect can be moderated with positive end-expiratory pressure (PEEP).

Positive pressure ventilation in the supine position in obese patients and during laparoscopic procedures is associated with reduced pulmonary compliance. This necessitates greater inspiratory pressures to deliver adequate tidal volumes. The Trendelenburg position exacerbates these effects significantly. Also, these patients are at increased risk of an increase in $pCO_2$ due to hypoventilation.

The supine position and general anesthesia decrease FRC. Pneumoperitoneum from laparoscopic surgery and the Trendelenburg position shift the diaphragm cephalad, further decreasing FRC, possibly to values less than closing volume. This causes airway collapse, atelectasis (more so in obese patients, because of the negative effects of thoracic wall weight and abdominal fat mass on pulmonary compliance), V/Q mismatch, potential hypoxemia, and hypercarbia. The use of PEEP raises intraoperative FRC, reduces hypoxemia, and may also help to reduce postoperative atelectasis. However, PEEP can reduce cardiac output, especially in the presence of a pneumoperitoneum; therefore, it should be used with caution.

## Cardiovascular

Changing from an upright position to the supine position results in an increase in venous return, which is associated with a redistribution of blood from the lower extremities into the central circulation. This increase in preload increases the cardiac output, with a concomitant reflexive decrease in heart rate, stroke volume (SV), and contractility. These changes are mediated through aortic and carotid baroreceptors via the vagus and glossopharyngeal nerves.

The body tries to maintain a stable blood pressure but the mechanisms that

accomplish this are altered with the addition of general anesthesia, neuraxial anesthesia, or PEEP. The effects of anesthesia on the cardiovascular system cause a decrease in the systemic vascular resistance (SVR) and reduce return of venous blood to the heart. The mechanisms that compensate hemodynamic changes are disrupted, causing the blood pressure to be more labile.

Placing patients in the Trendelenburg or reverse Trendelenburg position has a pronounced effect on systemic blood pressure while supine and under general anesthesia, more so than in awake and spontaneously breathing patients. The Trendelenburg position in awake and anesthetized patients results in an increase in pulmonary arterial pressure (PAP), central venous pressure, (CVP) and pulmonary capillary wedge pressure (PCWP), changes that may be poorly tolerated by patients with decreased cardiac reserve. In contrast, patients in the reverse Trendelenburg position under anesthesia are at risk for a decrease in cerebral perfusion, due to the hydrostatic pressure difference between the head and heart, where blood pressure is normally measured. For every 13 cm of vertical height difference of the head above the heart, the mean arterial blood pressure at the head will drop by 10 mm Hg.

Special attention is needed with a parturient, as the gravid uterus in the supine position can cause aortocaval compression leading to a supine hypotension syndrome and uteroplacental insufficiency. Every effort should be made not to place her in a true supine position; in order to maintain placental perfusion, a left lateral tilt of 15 to 30 degrees is usually sufficient to prevent inferior vena cava (IVC) obstruction and maintain placental perfusion. It's important to keep in mind that when the tilt position is used, the pregnant patient must be secured to the table to prevent fall and injury.

## Specific Complications

The supine position is related to numerous potential adverse outcomes and patient morbidity. The most significant of these are peripheral nerve injuries, injuries involving the eyes, and skin-related problems.

## Peripheral Nerves

Although nerve injuries are infrequent, they represent 16% of all closed claims, the second largest class of adverse outcomes in the ASA Closed Claims Study database. Internal and external compression, stretch, ischemia, direct trauma, and direct nerve laceration can all result in nerve injury. Although the mechanisms of the nerve injuries are not always understood, they are usually preventable with proper positioning and padding. The ulnar nerve and brachial plexus can commonly sustain damage if positioned incorrectly; however, any peripheral nerve may be subject to compression or traction injuries.

## Ulnar Nerve

The ulnar nerve is the most commonly injured nerve, accounting for 28% of peripheral nerve injuries. In the past, ulnar neuropathy was thought to be due to malposition of the elbow and compression of the nerve. Pronation of the arm, which may result in direct external pressure on the nerve, and extreme elbow flexion, puts the ulnar nerve at risk. Other factors, including male gender (males have a lower elbow fat content compared to women), prolonged hospitalization, anatomic variations at the elbow, and either thin or obese body habitus, may also increase the overall risk. In addition, a pre-existing subclinical compression can make the ulnar nerve more susceptible to injury. Ulnar nerve injury is also more common following cardiac surgery compared to noncardiac surgery.

To minimize the risk of injury to the ulnar nerve, the arms should either be tucked at the patient's side with the thumbs pointing upward or abducted to less than 90 degrees with the forearm supinated. Supination of the forearm in the abducted position puts the least amount of pressure on the ulnar nerve, decreasing the risk of compression-related injury. Padding can help to prevent direct compression of the ulnar nerve as it traverses the cubital tunnel. Flexion of the elbow greater than 90 degrees should be avoided, for example, when the arm is folded tightly across the chest.

## Brachial Plexus

To reduce the risk of brachial plexus injury in the supine position, the arm should not be placed in extremes of abduction, extension, or external rotation. Brachial plexus neuropathies can be avoided by ensuring abduction of the arms is kept to less than 90 degrees, limiting stretch or compression of the plexus. External rotation of the arm and posterior displacement should be avoided, and the head should be maintained in the neutral position. Lateral flexion of the head away from a fixed contralateral shoulder should be avoided, to reduce the risk of stretch on the contralateral plexus.

## Head

The head should rest on a soft, low-profile, circular foam piece or gel headrest to minimize pressure on the occipital area. The weight of the head should lie on the headrest and not hang unsupported above the operating room table, avoiding hyperextension of the neck. If possible, the head should be maintained in the neutral position. Alopecia may occur due to pressure on the back of the head during prolonged procedures. Repositioning the head every 30 minutes may prevent this.

## Skin

A reduction in perfusion leads to tissue ischemia and subsequent skin tissue breakdown. Pressure areas of concern during the supine position include the occiput, elbows, sacrum, calves, and heels. Careful padding of all pressure points is key for preventing pressure sores. Gel pads or ankle supports, which raise the heels off the table, can eliminate pressure points. Arms should not be wrapped too tightly, to prevent pressure on the skin from IV tubing or monitoring devices. Wrinkling of the sheets can occur when moving to the OR table, especially with obese patients. Every effort should be made to smooth out wrinkles under the patient, otherwise compromised circulation and pressure ulcers can occur. The common OR mattress is foam covered with nylon or vinyl; a gel mattress is an ideal alternative. Research results, however, have not provided a definitive answer regarding which type is best for preventing intraoperative skin injuries and pressure ulcers. When purchasing OR tables, the most important safety factors to take into consideration are the mattresses and the ability to evenly distribute body pressure to prevent circulatory disturbances and pressure ulcers at the bony prominences. Periodic pressure-relieving maneuvers may help to prevent skin problems.

## Eyes

Eye injuries are infrequent but can potentially result in serious complications. The most common type of injury in the supine position is corneal abrasion, which may occur in part because of reduced lacrimation during general anesthesia. There are no strict guidelines for how to protect the cornea and globe from abrasions or injuries; however, it is commonly accepted that taping the eyes shut helps, when possible. The risk of abrasion can be further reduced by use of lubrication; however, this is not a routine practice at many sites. Often, the use of lubricant is a matter of practitioner preference. Plastic corneal protectors coated with lubricant and inserted under the eyelids, usually by the surgeon, can be an effective and safe method of protection and can be easily removed at the end of the procedure. In some procedures, surgeons will suture the eyes closed if they are within the surgical field. At a minimum, using eye lubricant may be desirable if the eyelids cannot be taped or protected otherwise; this simple intervention might help to avoid a corneal abrasion. To help reduce the risk of direct pressure on the eyes, goggles can also be placed over a patient's eyes, with careful attention paid to the bony eye sockets and the bridge of the nose. Frequently, tubes and monitoring cables will cross over the face; this is not only a problem at the beginning of the case but throughout the procedure. Inspect the patient's eyes, ears, and nose frequently to ensure the face is free of pressure or possible trauma, even in a short procedure.

### TAKE HOME POINTS

- Safe positioning requires planning and good communication between all team members involved in the patient's surgical procedure.
- Adequate numbers of attentive and well-informed personnel are required at the beginning and at the end of a surgical procedure to facilitate safe positioning.
- Knowledge of physiologic changes associated with the position can help predict and prevent potential problems.
- All equipment should be secured and rechecked after every change in position.
- Sometimes complications do not become evident until several days after surgery.

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# Thinking Laterally—How to Safely Position a Patient in the "Sideways" Position for Surgery

Gregory Applegate, DO, Carlyann Miller, DO, and Raymond G. Graber, MD

An 88-year-old man with a history of hypertension, morbid obesity, and obstructive sleep apnea presents with a right hip fracture and is scheduled for a hemiarthroplasty. The surgeon plans a lateral position to help with exposure. What anesthetic approach should you chose for a lateral surgery? What are the anesthetic ramifications and potential risks of the lateral position? What supplies should you have readily available for the lateral position?

The lateral decubitus position is used to optimize surgical exposure for numerous types of surgery. A few examples include surgeries on the hip, lung, and kidney. Below we will discuss some important things to consider when planning and performing surgical procedures in the lateral position.

When the lateral position is planned, either general or neuraxial anesthetic techniques can be appropriate. The choice is frequently dictated by the type of surgery. For a patient with a hip fracture, either a general or spinal anesthetic could be appropriate, whereas a patient undergoing a thoracotomy will be managed with general anesthesia. The ideal case for a spinal is one in which you have an experienced surgeon doing a case that they routinely perform in a time that is predictably within about 2 to 3 hours. For example, a primary total hip at the author's institution can reliably be completed within 2 hours of performance of the spinal. On the other hand, there are cases where the time course is not predictable, such as acute care of orthopedic trauma, especially if there are residents working. For a long and unpredictable surgery, it is frequently easiest and safest to just use a general anesthetic. You have control of the airway, and it is easier to place extra intravenous, central or arterial lines if needed. If a neuraxial technique is desired in this situation, then a catheter-based technique such as an epidural or a combined spinal/epidural (CSE) should be used.

When considering a spinal anesthetic, you also need to consider issues such as whether the patient can tolerate the position, and what the airway will be like while

under sedation. If the patient has a high risk of airway obstruction, then you have to discuss with the patient whether they would be willing to be more awake. If the patient prefers to be oblivious, then maybe it would be safer to put an endotracheal to and control the airway.

If you plan to do a general anesthetic for a patient who will be the lateral position, it may be OK to place an LMA if it is a short case in a healthy patient with a good airway. However, for the vast majority of cases, we favor an endotracheal tube. The airway is secured—and you have no worries about the LMA getting displaced and obstructing the airway.

Another thing to think about is how to deal with the scenario where the surgery is taking longer than planned, and the spinal is wearing off. You need to have a plan B! The author's preference is to first try converting to total intravenous anesthesia (e.g., propofol/ketamine) and allowing the patient to breath spontaneously (a nasal airway is helpful). If this is not successful, then you have the choice of trying to secure the airway in the lateral position by direct laryngoscope or LMA insertion. The author's experience is that it is much easier to place an LMA in the lateral position then it is to intubate! Do not wait too long to implement your adjunctive anesthesia plans and do not **ever** tell the patient to "hang on" while their surgeon completes their hip replacement. That is simply unacceptable. If the surgery is in the finishing stages, the surgeon should be encouraged to use local anesthetic where possible.

There are multiple possible positioning-related injuries that can occur in the lateral position. **In our experience, patients are especially sensitive to perioperative injuries of any type—they present to the OR to get a problem fixed, and do not expect to come out of the OR with a new problem.** For example, the dependent radial nerve can be compressed posterior-laterally in the upper arm where it wraps around the humerus. The ulnar nerve can be compressed at the medial epicondyle of the elbow. The dependent brachial plexus can be injured by compression. The dependent peroneal nerve is vulnerable to compression against the head of the fibula. The dependent eye and ear, and breasts/male genitalia may be vulnerable to compression injury. Significant edema of the dependent periorbital tissues and lips and face can occur in prolonged lateral cases, especially if large volumes of IV fluid have been administered or if the bed is also positioned in Trendelenburg (head down).

We teach that the process of turning to the lateral position requires your utmost attention. First, make sure that all lines are free and in position so that they will not get pulled out with the turn. All facial piercings that will be dependent should already have been removed, no exceptions. The anesthesia provider is responsible for managing the head, neck and airway during the turn. Our practice is to disconnect the circuit from the endotracheal tube during the turn, so that no inadvertent snag on the circuit extubates the

patient. Typically, the patient is first turned laterally, then lifted a second time to insert an “axillary roll.” This roll is placed under the chest caudad to the axilla to prevent compression of the brachial plexus and axillary artery. Either a wrapped liter bag of intravenous fluid or a rolled blanket is commonly used for this purpose. Ensure that the roll is not directly against axilla by checking that at least 1 to 2 fingerbreadths can be placed between the roll and the skin of the axilla. A palpable pulse or good pulse oximetry waveform will confirm that the dependent arm axillary artery is not compressed.

After the patient is turned laterally, the dependant arm is typically placed on an arm board. The arm should be padded to prevent compression of the ulnar nerve at the elbow. The nondependent arm should mimic the dependent arm and is supported with either an arm-holding device or a secured stack of blankets. We usually favor an arm-holding device in our personal practices. This allows easy access to each arm so that IV sites can be observed, more lines can be started if needed, and also minimizes the weight on the dependent arm. If a stack of blankets is used, err on the side of a stack that is too tall as opposed to too short. Otherwise, the nondependant axilla may become compressed by the weight of the upper arm being drawn too perpendicularly and laterally (at too sharp an angle) across the chest. We were taught to visualize the arms of a lateral patient as in position to hold a large beach ball—there should be a natural and gentle rounded posture of the arms at the axilla and shoulders and the elbows should be just slightly flexed. After arm positioning, make sure that there are no pressure points between arm-holding devices and the patient’s skin, and that all intravenous lines are functioning properly.

The head should be kept in a neutral position and it will usually require two or more blankets to keep the head and neck in line with the spine. A foam “donut” pillow is useful to prevent compression of the ear and dependent eye. (Central retinal artery occlusion is a known complication of prone cases, but has also been reported in a few cases in the lateral position.) It is known that patients in the lateral position have a higher incidence of corneal abrasions, so an eye lubricant is typically used, and the eyes are secured shut with either tape or a transparent IV dressing. A pillow is commonly placed between the lower legs, which should not be overextended at the hips, knees, or ankles. Finally, a quick head-to-toe survey will prove useful to make sure that the eyes, ear, breasts, and genitalia are not compressed or pinched, the neck is in a neutral position and not laterally flexed, and that bony prominences are padded. Safety belts or stability devices such as a bean bag should be used to keep the patient stable. If the patient has a spinal anesthetic, we typically keep the patient awake during the positioning process. After the patient has been positioned, we will check with them to make sure arms, shoulders and neck all feel comfortable. After the patient confirms this,

it is time to start propofol.

During lateral positioned surgery, noninvasive blood pressure (NIBP) cuff values will vary between the dependent and nondependent arm. In comparison to an arterial pressure measured with transducer placed at the level of the heart, the pressures measured in the dependent arm will be about 10 to 15 mm Hg higher, while those in the nondependent arm will be 10 to 15 mm Hg lower.

Pulmonary physiologic changes do occur in the lateral position. The nondependent lung receives excess ventilation and the dependent lung experiences excess pulmonary perfusion. Fortunately, the ventilation–perfusion mismatch is clinically insignificant unless the patient has severe pulmonary compromise and/or is undergoing one-lung ventilation.

When moving a patient from supine to lateral position, the endotracheal tube is at risk of migration—which may result in either endobronchial intubation or extubation. It is good practice to confirm bilateral breath sounds by chest auscultation after changing from supine to lateral positions. For thoracic surgery with double lumen tubes or bronchial blockers, we strongly recommend fiberoptic bronchoscopy to reconfirm proper endotracheal tube placement after moving from supine to lateral.

Peripheral intravenous lines and arterial lines are easier to place prior to moving to the lateral decubitus position. These lines can be placed in the lateral position, but sites and access will be limited. The clinician must use his or her clinical judgment to decide what lines should be performed prior to positioning. Central line access should always be performed prior to turning the patient. Sometimes the dependent arm may be concealed under a stack of blankets. Be aware that if intravenous line flow is slow, it may not just be a compressed or positional IV, but an infiltrated IV. Excessive fluid delivered through a hidden infiltrated IV can lead to compartment syndrome.

## TAKE HOME POINTS

- When deciding on regional versus general anesthesia for the patient in the lateral position, make sure the planned regional can cover the duration of the planned surgery, and that the patient can tolerate the position.
- Prior to placing a patient in the lateral position, make sure you have the appropriate supplies: axillary roll, nondependent arm support, foam "donut" pillow, extra blankets/pillows for neck support.
- Remember that an operative case in the lateral position is really two moves—the first is the 90-degree rotation and the second is the lift for placement of the axillary roll.
- During the positioning process, check that the neck is neutral, and that known nerves at risk are not under undue compression or stretch. An arterial line or pulse-ox on the

dependent arm can help alert you to axillary artery compression.

- Ensure monitors and lines on the dependent arm are properly functioning after positioning.
- Understand the differences in blood pressure that may be obtained in the dependent and nondependent arm with NIBP.
- Be aware of the potential for endotracheal tube (ETT/DLT/bronchial balloon) migration when moving from supine to lateral. Check and recheck this!

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# Positioning Patients for Spine Surgery

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The obligatory positions required for spine surgery subject patients to significant risk above and beyond the inherent risk of the procedure itself. These risks include, but are not limited to, injury to the eyes, ears, nose, breasts, penis, extremities, and peripheral nerves. Peripheral nerve injury is a well-recognized anesthetic complication and is the second largest cause of malpractice actions in anesthesiology, accounting for 16% of claims. Minimizing potential injury to peripheral nerves through proper positioning and monitoring is extremely important.

Monitoring of somatosensory evoked potentials (SSEPs) is frequently utilized during spine surgery (75%) and is available in most institutions in the United States (94%). In addition to monitoring spinal cord function, SSEP can detect potential peripheral nerve injury during spine surgery. Conduction changes, such as a decrease in amplitude or an increase in latency of the signal, are believed to indicate impending upper-extremity nerve injury. Modification of the arm position by the anesthesiologist often improves the SSEP signal and may return it to baseline. Reversal of position-related SSEP changes can influence impending nerve injury and prevent postoperative peripheral nerve injury.

**The prone position is a dangerous position for patients.** Attention to securing the airway is very important, as it is difficult to re-establish an airway in the prone position. Though we must always be cautious regarding protection of the eyes, this position raises additional concerns. Both ophthalmic ointment and occlusive eye tape may be appropriate if the procedure involves the cervical spine; prep solution that comes into direct contact with the eyes can lead to corneal injury. Additionally, we must assure that there is no direct pressure on the eye, ears, or nose. Pressure on eye may lead to loss of vision due to central retinal artery occlusion. Pressure can lead to loss of function and/or a disfiguring ischemic injury. For the same reason, it is important when positioning chest rolls to assure yourself that the breasts in women and the genitalia in men are free from undue compression of any sort.

With regard to the patients' extremities, the mechanisms of nerve injury associated with surgical positioning and anesthesia are not completely understood. Peripheral nerve injury may be due to direct trauma or more commonly due to ischemia.

Compression of peripheral nerves or stretch beyond 15% of original length may cause peripheral nerve injury due to compression of intraneural capillaries. Diabetes, hypertension, tobacco use, and uremia are known to affect peripheral nerves and predispose them to injury; intraoperative conditions such as prolonged hypotension and anemia are believed to facilitate ischemic injury. Peripheral nerve injury has been associated with neurosurgical and orthopedic surgeries. Finally, certain operative positions are known to place patients at increased risk for nerve damage. During spine surgery the overall incidence of impending upper-extremity peripheral nerve injury, as defined by changes in the SSEP, is >6%.

The ulnar nerve and the brachial plexus are the most commonly injured neural structures during this type of surgery. Risk factors for ulnar nerve injury include male gender, very thin or very obese patients, and prolonged hospitalization for >14 days. Risk factors for brachial plexus injury include the use of shoulder braces, the prone head-down position, and some regional anesthetic techniques such as interscalene and axillary blocks.

There are five positions commonly employed during spine surgery: supine, arms out; supine, arms tucked; lateral decubitus; prone "Superman" position; and prone, arms tucked. The prone "Superman" position and the lateral decubitus position have been identified as high-risk positions for upper-extremity nerve injury, especially if the surgical procedure is prolonged. Techniques for minimizing injury in these positions are reviewed below.

The incidence of impending upper-extremity nerve injury during spine surgery in the supine arms-out position is 3.2%. Overstretch of the brachial plexus can occur as a result of abduction of the shoulder >90 degrees and should be avoided. Direct compression of the ulnar nerve against the medial epicondyle may occur, especially if the forearm is in the prone position. Placing the forearm in the supine or neutral position decreases pressure over the ulnar nerve at the elbow. Elbows should be padded to further protect the nerve from compression. Direct compression of the radial nerve in the spiral groove of the humerus can be avoided with proper padding. Overextension of the elbow should be avoided because it may stretch the median nerve. The patient's head and neck should ideally be maintained in a midline position. Tilting the head and neck laterally may stretch the contralateral brachial plexus.

The incidence of impending upper-extremity nerve injury during spine surgery in the supine arms-tucked position during spine surgery is 1.8%. The tucked arms should be placed in neutral positions to decrease the pressure over the ulnar nerve. The ulnar nerve should be padded at the elbow for additional protection. Shoulder tape, which is often applied by the surgeon to pull the shoulders down and maximize the lateral radiographic view of the spine, may compress the brachial plexus. The duration of

application of this shoulder tape should be minimized. The head and neck should be maintained in midline position. Placement of the patient's forearms on the lower abdomen should be avoided, as excessive flexion at the elbow joint can simultaneously stretch and compress the ulnar nerve.

The lateral decubitus position is a challenging position for the anesthesiologist. The incidence of impending upper-extremity peripheral nerve injury during spine surgery in the lateral decubitus position is 7.5%. Compression of the brachial plexus is the most common mechanism of injury. The dependent brachial plexus can be compressed between the clavicle and first rib as well as against the humeral head. Obese patients and patients placed in a head-down position are at higher risk, as compressive forces are augmented. A chest roll should be placed to elevate the dependent chest and decrease the likelihood of compression. The chest roll should not be placed in the axilla, but under the lateral, superior chest; the goal is to prevent compression of the contents of the axillae between the chest and humeral head. The dependent arm should be padded at the elbow and maintained in the supinated position to avoid compression of the ulnar nerve. To minimize the likelihood of brachial plexus stretch, abduction of the dependent and nondependent arm should be less than 90 degrees. Excessive flexion or extension at the elbow should be avoided. The elbow in the nondependent forearm should be padded, and lateral rotation of the shoulder should be avoided. The patient's head and neck should be maintained in a midline neutral position without excessive flexion or extension.

The prone "Superman" position is another challenging position with a relatively higher incidence of impending upper-extremity nerve injury (7%). Stretching forces on the brachial plexus is the commonest mechanism of injury. Again shoulder abduction beyond 90 degrees should be avoided, and the patient's head and neck should be in a neutral midline position. Elbows should be padded and the forearm and hand placed in a neutral position. Placing patients in steep head-down position should be avoided or limited if possible. Pressure from chest rolls should not be directly on the shoulders and the clavicle, as they may compress the brachial plexus, especially in obese patients. In women, the position of the chest rolls should be checked to ensure that there is no possibility of ischemic injury to the breasts. In men, the position of the lower roll should be checked to confirm that the genitalia are free from direct compression.

The prone arms-tucked position is relatively lower risk compared to the prone "Superman" and the lateral decubitus positions. The incidence of impending nerve injury in the prone arms-tucked position during spine surgery is 2.1%. Special attention should be given to positioning the head and neck as described in the previous paragraph. The forearms should be in neutral positions. Shoulder tape, applied to maximize the lateral radiographic view of the neck, should be minimized. The elbows

should be padded to avoid compression by arm sleds. Direct compression by the chest rolls is of concern as in the prone "Superman" position.

Attention to detail is one of the reasons for our specialty's superior safety record. When caring for patients undergoing spinal surgery, we must assume an integral role in positioning, monitoring, and interceding as appropriate.

## TAKE HOME POINTS

- The prone position can be dangerous for patients. Attention must be given to preventing injury to eyes, ears, nose, breasts, penis, extremities, and peripheral nerves.
- SSEP monitoring can be used to detect and prevent peripheral nerve injury during spine surgery.
- The lateral decubitus position and the prone "Superman" position are high-risk positions for nerve injury during spine surgery.
- Abduction of the shoulder beyond 90 degrees should be avoided because it stretches and may injure the brachial plexus.
- Excessive flexion of the elbow should be avoided; it stretches and compresses the ulnar nerve.
- Excessive extension of the elbow should be avoided because it stretches the median nerve.
- The forearm in the supinated position may be safest because of the decreased pressure on the ulnar nerve; the neutral position is a good second choice.
- Appropriate padding can minimize excessive pressure on the radial nerve in the spiral groove.

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# Sit Back and Relax? Implications of the Sitting Position in Shoulder and Brain Surgery

Evan Staszewski, DO and Michael D. Altose, MD PhD

The sitting position (beach chair position) is most commonly used during shoulder surgery, particularly arthroscopic procedures. This position has several surgical advantages compared with the lateral position: decreased incidence of brachial plexus traction neuropathy and neurovascular complications; decreased surgical duration; a more bloodless surgical field and reduced blood loss; better access to the shoulder from both the anterior and posterior aspect; more physiologic arm movement by the surgeon; and easier conversion to an open procedure. There are anesthetic advantages as well, including: better access to the airway, face and thorax; lower airway pressures and better diaphragmatic excursion which can improve ability to ventilate; increased vital capacity and functional residual capacity (FRC); better access to extremities; and less risk of swelling of the tissues in the eyes, face, and airway.

In the sitting position, the arms are pulled caudad by gravity, and traction on the shoulder muscles can lead to stretching of the brachial plexus and other neurovascular structures. The arms therefore must be supported, while avoiding pressure on the ulnar area of the elbow, a common site of nerve injury. This can be done with padded arm supports, or the arms can be secured across the patient's abdomen. Hips should be flexed 45 to 60 degrees and knees should be flexed about 30 degrees to reduce stretching on the sciatic nerve; but excessive knee flexion should be avoided to prevent abdominal compression. Ensure there is no compression of the common peroneal nerve, which is also commonly injured. Feet should be supported and padded, avoiding excessive plantar flexion.

Shoulder surgery in the sitting position can be done under general or regional anesthesia, or a combination. The patient is seated at an angle of 30 to 90 degrees from the horizontal plane, with the head stabilized on a head rest using a specialized face mask or a wrap of gauze or tape. Some anesthesiologists prefer to secure the airway with an endotracheal tube, but, many shoulder surgeries can be done with a supraglottic airway if the surgeon does not require neuromuscular blockade and the patient is an

appropriate candidate.

Several hemodynamic changes occur in the sitting position, primarily due to venous pooling in dependent tissues. Pulmonary and systemic vascular resistance increase, while venous return, cardiac output and cerebral perfusion pressure (CPP) decrease, and hypotension may occur. Hypovolemia can also lead to V/Q mismatch, due to decreased perfusion of the upper lung. Hypotensive bradycardic events have been described in patients who have regional blocks using epinephrine, and are thought to be caused by the Bezold–Jarisch reflex.

The decrease in CPP can lead to devastating complications including cerebral ischemia, retinal ischemia, and spinal cord injury. Surgeons may request deliberate hypotension in order to provide a bloodless surgical field and improve visualization through the arthroscopy camera, which can increase the risk of hypoperfusion. Many sources recommend keeping systolic blood pressure (SBP) >90 mm Hg and mean arterial pressure (MAP) >70 mm Hg to minimize risk of cerebral hypoperfusion. Ideally, SBP and MAP should be maintained within 20% of baseline values.

There are several strategies to minimize the risk of cerebral hypoperfusion. First, most sources recommend paying attention to the difference between CPP and MAP, recognizing that for each 1.25 cm elevation of the head above the level of the heart, local arterial pressure is reduced by approximately 1 mm Hg. This difference becomes quite significant in the sitting position, especially if the blood pressure cuff is placed on the leg. **Incremental positioning, intravenous fluids and vasopressors can attenuate the severity of hypotensive episodes and preserve cerebral oxygenation, while elastic stockings and active leg compression devices can help maintain venous return**. One study has suggested that adding PEEP (5 cm $H_2O$) reduces the amount of hemorrhage in the surgical field and increases surgeon satisfaction during arthroscopic shoulder surgery, without requiring controlled hypotension. Maintaining end-tidal $CO_2$ in the 40 to 42 mm Hg range (as compared with 30 to 32 mm Hg) can provide better cerebral blood flow and oxygenation. Cerebral oximetry may be appropriate in higher-risk patients to identify cerebral hypoperfusion. Very high–risk patients may benefit from using regional anesthesia only without general anesthesia, which will better preserve cerebral autoregulation.

The sitting position is also used, albeit infrequently, during neurosurgical procedures involving the posterior cervical spine and the posterior fossa. Surgeons may prefer this position rather than the prone position due to improved surgical exposure and decreased blood in the surgical field. The head is usually fixed in place with a 3-pin head holder that is attached to the operating table. It is highly preferable to secure the frame to the back portion of the bed (and not the portion that supports the patient's thighs). This will allow the head of the bed to be flattened in the event of venous air embolism (VAE),

severe hypotension, or cardiac arrest.

Flexion of the cervical spine may be needed to improve surgical exposure. Excessive cervical flexion or rotation should be avoided, as it can impede arterial blood flow (causing cerebral hypoperfusion) as well as venous blood flow (leading to venous congestion of the brain). Extremes in neck flexion/extension can impair spinal cord autoregulation, especially when coupled with a reduction in hemodynamic parameters, and spinal cord infarction and quadriplegia have been reported. Excessive cervical flexion can also lead to obstruction or kinking of the endotracheal tube in the pharynx and place significant pressure on the tongue causing swelling. In adults, one should try to maintain at least 2 fingerbreadths (2 to 3 cm) of distance between the mandible and the sternum. If transesophageal echocardiography (TEE) is used for air embolism monitoring, extra caution should be taken since the esophageal probe increases the potential for compression of laryngeal structures and the tongue. Similarly, large oral airways or bite blocks should be avoided.

As discussed above, the sitting position may lead to decreased cardiac output and cerebral perfusion. During neurosurgical procedures, most anesthesiologists prefer to position the arterial pressure transducer at the external auditory canal (Circle of Willis) to more accurately reflect true CPP. The dysrhythmias that can occur with surgical manipulation of the cranial nerves or brainstem (bradycardia, tachycardia, PVCs, asystole) may have an exaggerated effect on cardiac output in the sitting position.

Elevation of the surgical field above the heart can reduce dural sinus pressure by up to 10 mm Hg. These dural venous sinuses cannot collapse because of their bony attachments, so the risk of VAE is a constant concern. **If enough air is entrained, arrhythmia, desaturation, pulmonary hypertension, circulatory compromise, or even cardiac arrest may occur.** If an intracardiac shunt is present (e.g., patent foramen ovale), even small amounts of venous air may result in a stroke or myocardial infarction as a result of paradoxical embolism. Nitrous oxide is often avoided, as it increases the size of intravascular bubbles (but it has not been shown to worsen perioperative morbidity in patients undergoing posterior fossa surgery). Some centers perform screening echocardiography before considering the sitting position for neurologic surgery. In the OR, early detection of entrained air with the use of TEE or precordial Doppler ultrasound may decrease the incidence and severity of VAE, and placement of a central line to aspirate large collections of air from the right heart is advised.

## TAKE HOME POINTS

- Surgery in the sitting position has advantages for the anesthesiologist and surgeon, but patient injury can occur if precautions are not taken.

- To avoid spinal cord or nerve injury, avoid excessive neck flexion/extension/rotation, ensure that arms are properly supported, and take steps to prevent compression of the ulnar and peroneal nerves.
- Decreased cardiac output and CPP in the sitting position can have profound hemodynamic and neurologic sequelae. Be aware of the difference between noninvasive blood pressure cuff measurements and CPP.
- Cerebral oximetry and/or a regional-only anesthetic may be helpful when caring for patients at very high risk for cerebral hypoperfusion.
- VAE can occur during craniotomy in the sitting position, and should be avoided in patients at high risk for paradoxical embolism. Be prepared to detect and manage intraoperative VAE.

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# Individuals With Cerebral Palsy and Other Spastic Disorders Need Your Best Positioning Prowess

Brandon Michael Togioka, MD, Benjamin C. Conner, MSc MD/PhD3, and Carol Bodenheimer, MD

An 18-year-old female patient with cerebral palsy and contractures of her knees and hips presents to you for an MRI under anesthesia. The patient first presented to the MRI technician yesterday, but they were unsure how to position the patient on the MRI table. There is a note in the anesthesia posting requesting neuromuscular paralysis so that "the patient's contractures can be straightened for imaging." Is this a reasonable request? How do you proceed?

Positioning is quite important for preventing postoperative pain and neurologic complications. Over the last a few chapters you have learned how to position patients to facilitate surgery while minimizing physiologic perturbations and the opportunity for neurologic injury. Now we are going to take it up a level. Patients with cerebral palsy (CP) have musculoskeletal deficits that make them among the most prone to positioning-related pain and injury.

While there has yet to be a formally agreed upon definition for CP, most providers would agree that it is a nonprogressive disease of motor dysfunction related to central neurologic pathophysiology that is sustained very early in life. CP is the most common cause of severe childhood motor disability. While early studies seemed to point to a peripartum asphyxia etiology, intrapartum hypoxia has recently been estimated as the cause in only 6% of all patients with CP. The incidence of CP is estimated at between 2 and 2.5:1,000 live births.

There are different types of CP, based upon the area of brain injury. The most common type of CP is spastic, which is due to lesions in the cerebrum. Patients with spastic CP often have normal intelligence. Individuals with spastic CP have an imbalance between their excitatory and inhibitory neural impulses. It is believed that this imbalance (due to a lack of inhibitory signals from the brain) leads to a relative

excess of excitatory impulses, overexcitation of the muscle, and a state of constant contraction. Over time, the muscle's state of constant contraction leads to permanent shortening due the fibrosis, which limits range of motion. Other types of CP include dyskinetic CP, involving injury to the basal ganglia, and ataxic CP, involving injury to the cerebellum. It is also possible to have a mixed form of CP that includes characteristics of multiple forms. For purposes of this chapter, we focus on spastic CP as it is the contractures that cause most positioning issues.

If there is one lesson to remember from this chapter, it is that patients with CP should be put in a comfortable position, which minimizes muscle tone. If possible, allow the patient to place themselves on the operating room table while awake, so that you can see what is natural and a neutral position for them. Consider having the care provider in the room for initial positioning to decrease patient fear. The patient will naturally place themselves in a position that minimizes the chance for skin, muscle, and bone damage; however, because of the difference in surfaces, this may not avoid skin damage. Please note that the neutral position for a patient with CP may not result in symmetric joint placement. This is okay. After the patient is asleep, the provider can make minor adjustments in positioning. General anesthesia and neuromuscular paralysis can facilitate final positioning; however, keep in mind that it is not wise to extend a joint that does not want to stretch. This can lead to permanent muscle, nerve, and bone damage. Patients with CP need postural support in ways that patients without CP do not. This may mean using extra pillows, cushioning pads, and adjunct support structures. As is the case for all patients, extremities should never hang under their own weight, but rather have a support structure built up to them.

Individuals with CP have an underdeveloped musculoskeletal system and osteopenia, especially of the lower extremities. This predisposes them to low-energy fractures, or fractures from an insult that would not usually cause injury. Over one quarter of all CP patients experience a fracture before adulthood. Many of these fractures occur during positioning or transfers. Because these injuries occur during an insult that one would typically not expect to cause injury, many of these diagnoses are delayed. In other words, you may cause a fracture during patient positioning without even knowing it. Remember, neuromuscular blockade will abolish spasticity-related joint limitations, but not contractures (due to permanent shortening of the muscle and tendon). Again, forceful positioning is a no-go in patients with CP.

Positioning the hip deserves special attention when it comes to patients with CP. As we previously discussed, patients with CP often have abnormal gait, sitting posture, muscle tightness, and spasticity which leads to abnormal loading on joints. Bones remodel in response to stress leading to osteophyte formation, bone deformation, and osteoarthritis. The hip is particularly prone to dislocation in CP as spastic muscle

forces lead to nonuniform stress across the femoral head. This concentrates stress on the superolateral part of the femoral head leaving the rest of the femoral head relatively unloaded and predisposed to separating from the acetabulum. Hip subluxation, or dislocation, during transfers has been documented in both adult and child patients with CP. Preoperative questioning of individuals with CP should include questions about prior hip dislocations. In order to prevent hip dislocation, special attention must be paid in supporting the hip and pelvis during transfers and final positioning on the operating room table.

Patients with CP are prone to complications from skin injury. Patients often have metabolic derangements and also often have thin, poorly vascularized skin, a thin subcutaneous fat layer, and less contractile muscle fibers for padding. This can lead to skin tears, pressure ulcers, and muscle necrosis. Careful attention to common pressure points is warranted to help decrease the chance for skin injury. Common areas that require padding in all patients include the following: the ears, the elbows, the hips, the knees, the heels, the back of the head, and any areas where lines or drains are entering the patient, such as the site of a G-tube button. In addition, every patient with CP will have additional areas where they are prone to skin injury secondary to their particular pattern of contractures. These areas will typically be obvious at the time of positioning. An intermittent massage (or repositioning if possible) to improve circulation in any area of concern during long surgery can also be helpful.

Hypothermia is the most commonly encountered adverse event in the perioperative period for patients with CP. Patients with CP are prone to hypothermia because they typically lack muscle and fat while having a compromised central nervous system, which may lead to abnormal thermoregulation. Hypothermia has many deleterious side effects such as an increased rate of wound infection, prolonged neuromuscular blockade, delayed emergence, postoperative shivering, and potentially increased perioperative blood loss. Preventing hypothermia should always be on the provider's mind when positioning patients with CP. This can be accomplished by using convective warming blankets, warmed intravenous fluids, humidification of gasses, and controlling the operating room temperature.

Lastly, it is worth noting that positioning difficulties in patients with CP do not go away once the operation is over. Positioning in the PACU, ICU, and floor patient locations is equally, if not more, important as patients will typically spend more time in these locations. Providing adequate analgesia in the postoperative period is of utmost importance for patients with CP. Ineffective analgesia can lead to muscle spasms, worsening pain, further immobility, and a higher risk for skin breakdown. As communication can be difficult in patients with CP, continuous pain regimens may be better than on-demand regimens. Behavioral indicators of inadequate pain control are

very important to pay attention to. Regional anesthesia has been used safely, but keep in mind that regional anesthesia also typically implies less mobility, which can predispose to skin necrosis.

## TAKE HOME POINTS

- CP is a nonprogressive disease of motor dysfunction that is sustained in utero, during birth, or immediately thereafter.
- When positioning patients with CP, place them in a comfortable position that minimizes muscle tone.
- Do not force joints that do not want to stretch as this can lead to permanent muscle and nerve damage or bone fracture.
- Patients with CP are especially prone to hip dislocation during transfers and positioning.
- When positioning patients with CP, pay special attention to avoid skin breakdown and hypothermia.

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# Use Extra Care in Positioning Patients Who Have Had Amputations

Carol Bodenheimer, MD and Catherine Marcucci, MD

With over 2 million people living with limb loss in the United States, caring for patients with prior amputations is more common during other surgical procedures. All anesthesia providers must take extra care with patients with amputations to avoid positioning injuries. Be aware that limbs that have sustained partial amputation have undergone subtle but very real changes in musculoskeletal structure, skin integrity, and somatic and autonomic innervation. The contralateral limb is at risk as well and care must be taken with its positioning.

The joints proximal to an amputation are often affected on both the contralateral and ipsilateral sides. For example, because of increased weight bearing in the contralateral leg, it is very common after lower-limb amputation for the contralateral hip to develop significant osteoarthritis. This is true even for patients who use a prosthesis. On the ipsilateral side in above-knee amputations, a hip flexure contracture results from immobility (more time sitting) and a hip abduction contracture from loss of the insertions of the adductors to the distal femur. On the ipsilateral side in below-knee amputations, a knee flexion contracture develops as a result of impaired mobility and loss of quadriceps extension strength. This is very common even in relatively young and active patients and will predispose a patient to injury in any position involving extension at the knee, such as the simple supine position. A pad below the distal thigh allows mild knee flexion and protects the integrity of the skin at the end of the stump.

In all types of amputation, there can be subcutaneous fibrosis at the amputation site that puts the overlying skin at risk because of increased tension and decreased blood flow. In many patients with amputations, the underlying medical reason for the amputation (diabetes or vascular disease) may mean that the skin of the residual limb is at high risk for skin breakdown independent of amputation. Up to 55% of those with an amputation due to medical disease will require amputation of the second leg within 2 to 3 years. Even in patients whose limb loss was due to trauma, there is a higher risk of skin breakdown because of concomitant skin disorders such as contact dermatitis and

verrucous hyperplasia. Patients who show skin breakdown or ulceration on a residual limb should be positioned so that there is minimal chance of further pressure injuries. Perturbations in both the somatic and autonomic nervous systems can cause patients who have had amputations to experience a variety of hypersensitivity and chronic pain syndromes, including causalgia and phantom limb pain. Positioning injuries therefore can also cause an acute-on-chronic pain syndrome that can be especially distressing to the patient.

**Upper limb loss is a less common occurrence—the ratio of upper limb to lower limb amputation is 1:4. However, positioning a patient with an upper limb amputation may be even more complex than a patient with lower limb amputation.** Padding for support must be balanced with the need to access the upper extremities for monitoring access intraoperatively. Upper residual limbs may have nerves with less muscle and skin protection, and special attention to nerve protection is appropriate. Surgical positioning in lateral or prone will be especially challenging in patients with high above-elbow or forequarter (in which the arm, scapula and clavicle are all removed) amputations.

It is now understood that the perception of pain involves cortical processing of afferent input to the nervous system. There is also a tremendously complex interplay among all types of pain and psychological and emotional resilience. Amputation patients have an array of psychological "defenses" pertaining to their amputations, ranging from Vietnam War veterans who say simply, "Stepped on a toe-popper my third week in-country," as if there is nothing more to the story, to patients who carefully guard their residual limbs. Patients who have had recent amputations may also be prone to depression. Ask if there is pain in the limb and discuss the plan for careful positioning with the patient. This can lessen anxiety, which is a good start to preventing pain. It is also appropriate to check for changes in the usual pain pattern during the postoperative check.

## TAKE HOME POINTS

- A new generation of war-wounded patients will be entering care in both civilian and veterans hospital—a significant percentage of whom will have had one or more amputations.
- Be attentive to changes in musculoskeletal structure, skin, and innervation.
- Above-knee amputees can have hip flexion and abduction contractures requiring positioning that must account for this.
- Below-knee amputations can result in knee flexion contractures.
- Upper-extremity amputations are less common than lower-extremity amputations but more complicated to position.

- Subcutaneous fibrosis can put the overlying skin at increased tension with decreased underlying blood flow.
- Positioning injuries can result in acute-on-chronic pain in amputated limbs.
- If possible, involve the patient in the positioning before induction of anesthesia.

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# 134

# Never, Ever Fire

C. Tyler Smith, MD and Brian T. Gierl, MD

Operating room fires can occur away from the patient, on the patient, or worse—inside the patient. Each fire location has its own consequences and subsequent management. The Emergency Care Research Institute (ECRI) estimates that in the United States the annual incidence of surgical fires in 2012 was 200 to 245 fires, which is down from 550 to 650 reported in 2009. Of fires reported, 76% occurred in the outpatient setting and 81% are cases in which the patient received Monitored Anesthesia Care. Surgical fires were distributed as 34% in the airway, 28% on the head or face, and 38% elsewhere on or inside the patient. A fire causing harm to a staff member or a patient is a never event because with appropriate preventive strategies they can be entirely avoided, yet one occurs every weekday in the United States. This chapter will take you through the risks and how to avoid them.

We have all heard of the fire triad: oxidizers, fuels, and ignition sources. But what are the usual suspects in the OR? Oxygen is the most common oxidizer in the operating room, and is reported in 95% of all fires in the ASA Closed Claims Database. Open sources of oxygen (e.g., nasal cannula, simple facemask) are the major source of oxidizing agents for surgical fires. **Remember that laughing gas is not funny, nitrous oxide will support combustion almost as well as oxygen.** Fuels are the combustible materials that maintain a fire. Common fuels in the operating room include prep solutions—that is, 2% chlorhexidine in 70% isopropanol—surgical drapes and covers, dressings, hair, anesthesia equipment, and other equipment. Realize that an alcohol-based prep solution dries quickly on open skin, but requires more time to dry in hair or under a drape. A variety of other things have rarely been reported to burn, including bone cement. Bowel gas is both very putrid and highly flammable. An ignition source is any source of energy (open flames, sparks, static electricity, and hot surfaces) that initiates the process of igniting a fire or explosion. Caffeine is a source of energy for anesthesia providers but does not ignite. Ignition sources in the operating room include Electrosurgical Units (ESUs), surgical lasers, fiberoptic lights, drills, defibrillators, $CO_2$ absorbers (sevoflurane and dehydrated soda lime), or short circuits in OR

equipment. In a report from the ECRI, 58% of fires involved ESUs, 38% involved fiberoptic cords, and 3% involved lasers. When oxidizers, fuels, and ignition sources are all present in the OR, patient surgical fire risk assessments should be taken.

## Risk Assessment

The risk of fire in the operating room should be assessed for each patient in every type of case. This assessment should be done jointly by the whole perioperative team—including the surgeon, anesthesiologist, and nursing staff, and can be incorporated into the preoperative timeout or "huddle" process. A simple tool has been developed to facilitate this process—the "Silverstein Fire Risk Assessment Tool" (Table 134.1). This tool basically checks whether you are providing free oxygen near the surgical field and if you are using an energy source that could ignite it. Answer these three questions and add 1 point for each yes answer:

A score of 3 out of 3 is a warning that the operation carries a high risk for surgical fire. Score of 2 indicates intermediate risk. And if only one or no conditions are met the operation is considered low risk. This risk assessment will guide what preventative measures should be used for the operation.

## Preventative Measures

The appropriate use of preventative measures is the key to avoiding surgical fires and communication between the various OR teams is the first line of defense. The fire triad and its components can be broken down into which team member has the most influence. Anesthesiology controls the oxidizer, while surgeons have the ignition source and nursing primarily influences the fuel. However, all members of the teams play crucial roles in minimizing all components of the fire triad. In low to intermediate surgical fire risk procedures based on the "Silverstein Fire Risk Assessment," standard fire precautions should be followed. These precautions include limiting the oxygen to the lowest $FiO_2$ that maintains patient oxygenation (ideally <30%). If using an open oxygen delivery system, limit the oxygen flow to as low as necessary to maintain adequate oxygenation. **No matter how low the oxygen flow, a flow rate of pure oxygen can accumulate under a drape and a single touch of the ESU can ignite that high concentration and create a fire.** A hose barb on the outlet of an anesthesia gas machine allows the provider to administer gas with a known oxygen flow rate, limiting the oxygen concentration. A suction tube under the drape will draw in room air and dilute the oxygen concentration to an extent proportional to the flow rate through the suction versus the flow rate of oxygen. In short, there are a lot of variables in that situation and it is not easy to determine the local oxygen concentration; **anyone who has scavenged high flow oxygen with a suction catheter in the past should realize that**

**just because there hasn't been a fire, it doesn't mean that you have a safe situation or that you won't have a fire during your next case.** It should be noted that if the $FiO_2$ is >30% prior to introducing an ignition source into the surgical field, the surgeon should wait 3 to 5 minutes to allow appropriate dissipation of the accumulated oxygen. You can briefly sample such an area with your capnogram tubing to determine the local oxygen level. Also, prep solutions should be allowed to adequately dry (for at least 3 minutes or per manufacturers recommendations), drapes should be configured in such a way that oxidizing agents do not accumulate, ignition sources should be protected by storing them in their appropriate holsters and away from surgical fuels, and appropriately reinforced endotracheal tubes should be used with lasers—although no ETT is LASER-Proof. In high-risk surgical fire procedures, standard fire precautions should be employed in addition to avoiding open oxygen delivery systems: avoid nitrous oxide, ensure that a syringe and basin containing saline is accessible, fill the endotracheal tube cuff with normal saline, use wet sponges, avoid ESU if possible or if not feasible then use alternative ESU devices such as bipolar ESU or a harmonic scalpel. Bipolar ESU requires less energy and has less current leakage than monopolar electrodes, making fires much less likely but not impossible—**nothing is impossible**. Class 4 LASERS by definition transfer enough energy to ignite a fire and include $CO_2$ and YAG LASERS; class 3 LASERS cannot ignite a fire. Any facility that uses LASERS should have a LASER Safety Officer that can address your concerns.

**Table 134.1 ■ Silverstein Fire Risk Assessment Tool**

| Item | +1 Point for each "Yes" response |
|---|---|
| **Is the surgical site or incision above the xiphoid process?** | |
| **Is there an open source of oxygen including nasal cannula or simple facemask?** | |
| **Is there an available ignition source such as ESU, laser, fiberoptic light source, etc.?** | |
| **Total:** | |

## Management of the Surgical Fire

When the fire occurs each team member plays a vital role in minimizing harm or possibly eliminating it entirely. A fire inside the operating room but away from the patient warrants activation of the emergency response system. A carbon dioxide fire extinguisher should be utilized. A water extinguisher will damage operating room equipment and cause more sparks that could ignite more fires—your bad day just got worse. The acronym RACE serves as a guide in the initial steps of fire management.

## Race to Fire Safety

**R**emove the patient from the burning source
**A**ctivate the alarm system
**C**onfine the doors to the OR once the patient has been evacuated
**E**xtinguish the fire.

Staff should be familiar with the location of medical gas supply shut-off valves to limit the entry of oxidizing agents into a large fire.

In the event of a fire located on the patient, the drapes should be doused with water and quickly removed. It is important to remove the drapes in a horizontal direction, away from the patient's airway to prevent mixing of oxidizing agents. The anesthesiologist should discontinue the oxygen supply and ventilate with air until the fire has been extinguished. If the fire is located in the patient's airway, the anesthesiologist should immediately remove the endotracheal tube and shut off all gas flow to the circuit. The sequence of events has been a controversial topic, but the time to remove the endotracheal tube (ETT) and turn off gas flow should be dictated by what can be completed first by the anesthesiologist depending on the proximity of items at the time of the fire—if the ETT is within arm's reach but the gas flow meter is not you should pull the ETT before turning off the gas and vice versa. Saline—or any fluid—should then be poured into the patient's airway. It is probably best to pour saline down a burning tube before removing it from the patient, but that should be weighed against the time required to obtain the fluid. Reassessment of the patient's airway will allow the anesthesiologist to verify the airway fire has resolved and subsequently proceed to management of the postsurgical fire with preparations to send the fire victim to an American Burn Association (ABA) burn center.

## Postsurgical Fire Management

After it has been verified that the fire has been exhausted, it is essential to establish ventilation and oxygenation. Bag mask ventilation should resume with the minimal $FiO_2$ that the patient can tolerate, minimizing the oxidizing agent until a secured airway can be established or the procedure comes to completion. Bronchoscopy may be warranted in

large fires to assess the structural damage to the lungs and the airway. However, antibiotics and steroids that have been described in the literature, are not universally adopted.

Admission to an ABA burn center should be considered if the patient meets requirements: evidence of inhalational injury, full thickness burns of >10% total body surface area, burns involving the eyes, ears, hands, feet, or perineum likely to result in cosmetic functional impairment, or chemical or electrical burns.

## TAKE HOME POINTS

- Although rare and preventable, surgical fires occur every day in the United States, and it is important to prevent them and to be prepared in the instance that one happens. And OR fires are something that you should expect to see in your professional lifetime. Most of the editors have seen at least one. They happen in a flash—literally and figuratively. Cathy Marcucci once saw a surgeon set his own surgical gown on fire.
- The fire triad components are: the oxidizer, the fuel, and the ignition source.
- Communication is paramount in the risk reduction of surgical fires.
- The "Silverstein Fire Risk Assessment Tool" assesses whether an ignition source will be near the oxygen supply.
- Preventative measures should be employed based on the risk of surgical fire determined at the beginning of the procedure.
- Consider the use of an oxygen blender to deliver gas with a set oxygen concentration of no more than 30%; even oxygen administered as a low flow rate can pool under the drapes and create a fire hazard.
- In the event of an airway fire, the endotracheal tube should be removed and fresh gas flow should be turned off in whichever succession is fastest.
- Drapes, airways, and airway devices (ETT or LMA) should be doused with saline and the surgical fuel should be removed as quickly as possible.
- Ventilation and oxygenation should be reestablished once the fire has been exhausted.
- Postsurgical fire management may include bronchoscopy and admission to an ABA burn center. Any patient who suffers an airway fire should be treated at a burn center.

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# Malignant Hyperthermia: If You Get to the Point Where You See an Elevated Temperature, It's Already Happening

James C. Opton, MD

Malignant hyperthermia (MH) is a clinical syndrome characterized by uncontrolled skeletal muscle metabolism. First defined in 1960 by Denborough and Lovell, it is classically "triggered" by volatile anesthetics and the depolarizing muscle relaxant succinylcholine in genetically susceptible individuals. MH is caused by uncontrolled calcium release in skeletal muscle cells as a result of abnormal function of the ryanodine receptor (RYR1). Diagnosis can be made clinically, by caffeine–halothane contracture testing of a muscle biopsy specimen, or by genetic testing. The caffeine–halothane test is very sensitive. However, it is invasive and expensive (about $800). Genetic testing for one of several known mutations of the RYR-1 genes is done via a simple blood test. Although it is not very sensitive, it is very specific and much less costly (about $200).

The overall incidence of MH-susceptible patients in the general population is hard to estimate, because it is a "cluster" disease. However, in 2005, there were 12 confirmed cases and an additional 10 probable cases in the United States, according to an official at the Malignant Hyperthermia Association of the United States (MHAUS).

MH can occur at any time during anesthesia or in the immediate postoperative period. It is the standard of care to ask every patient exposed to a triggering agent if he or she has a family history suspicious for MH ("Has a family member ever had a dangerous or unusual reaction to anesthesia?," etc.). **Although it is a rare disease, it is an important one in terms of anesthetic practice—anesthesiologists are expected from a medical/legal standpoint to be able to recognize and treat MH even if they are seeing it for the first time.**

The most consistent indicator of potential MH is a large increase in end-tidal carbon dioxide. End-tidal $CO_2$ can double or triple in minutes (although it may increase over hours). Masseter rigidity is another early sign, and tachycardia, arrhythmias, unstable or rising blood pressure, cyanosis and mottling, myoglobinuria, and tachypnea follow.

Whole-body rigidity is a specific sign of MH and is seen in the limbs, abdomen, and chest if muscle relaxants have not been used. Respiratory and metabolic acidosis indicate fulminant MH and are typically followed by temperature elevation, a late sign. The temperature rise can be rapid and may exceed 43°C. Rhabdomyolysis and disseminated intravascular coagulation (DIC) may also occur. Death is usually from cardiac arrest secondary to acidosis or hyperkalemia. In the dantrolene era, mortality from MH is less than 10%.

## Treatment of Acute MH

- Call for help! Get dantrolene!
- Discontinue volatile anesthetics and succinylcholine.
- Hyperventilate with 100% oxygen at high fresh gas flows.
- Give dantrolene 2.5 mg/kg by intravenous (IV) bolus. Repeat dose as needed until signs of MH are controlled.
- Place two large-bore peripheral IV lines and an arterial line.
- Treat acidosis with bicarbonate as guided by blood gas analysis.
- Actively cool patient with IV cold saline, nasogastric lavage, rectal lavage, and surface cooling. Discontinue cooling when temperature has fallen to 38°C.
- Treat hyperkalemia with hyperventilation, bicarbonate, insulin with glucose. Life-threatening hyperkalemia should be treated with calcium.
- Dysrhythmias usually respond to treatment of acidosis and hyperkalemia. If not, use appropriate antiarrhythmics with the exception of calcium-channel blockers.
- Serially monitor end-tidal $CO_2$, arterial blood gases (ABG), serum potassium and other electrolytes, urine output, and international normalized ratio (INR)/prothrombin time (PTT).
- Ensure urine output of at least 2 mL/kg/h by hydration and/or diuretics. In severe cases, consider more intensive monitoring for volume status and cardiac output, such as with a noninvasive cardiac output monitor (pulse pressure or stroke volume variation monitor) or pulmonary artery catheter.
- Call the MH Hotline.

## Treatment of Postacute MH

- Observe in intensive care unit (ICU) for at least 24 hours, as recrudescence may occur.
- Give dantrolene 1 mg/kg IV every 4 to 6 hours for 24 to 48 hours after the episode.
- Follow arterial blood gases, creatine kinase (CK), potassium, coagulation factors, urine myoglobin, and temperature until they return to normal. CK may stay elevated for up to 2 weeks.

- Report patients to the North American MH Registry of MHAUS and refer patients to MHAUS for information.

## What to Stock in the Malignant Hyperthermia Cart

The MHAUS is very specific about what needs to be stocked in the MH cart. In addition to the standard American Society of Anesthesiologists (ASA) monitors, all locations where general anesthesia is administered should have a posted plan to treat MH; a means to continuously monitor end-tidal $CO_2$, blood oxygen saturation, and core body temperature; and a means to actively cool a patient. A malignant hyperthermia cart stocked with the following should be immediately available wherever general anesthesia is administered:

## Drugs

) Dantrolene sodium for injection: 36 vials (each able to be diluted at the time of use with 60 mL sterile water). With the conventiionally available dantrolene, mixing of the drug can take 15 to 20 minutes. A new injectable solution of dantrolene sodium (Ryanodex) was approved by the FDA in 2014, which will be available in 250-mg single-use vials. This formulation has the potential to reduce the time needed to prepare and administer the correct dose of dantrolene during an MH crisis.
) Sterile water for injection USP (without a bacteriostatic agent) to reconstitute dantrolene: 1,000 mL × 2.
) Sodium bicarbonate (8.4%): 50 mL × 5.
) Furosemide 40 mg/ampule × 4 ampules.
) Dextrose 50%: 50-mL vial × 2.
) Calcium chloride (10%): 10-mL vial × 2.
) Regular insulin 100 U/mL × 1 (refrigerated).
) Lidocaine for injection, 100 mg/5 mL or 100 mg/10 mL in preloaded syringes (× 3). Amiodarone is also acceptable. Advanced cardiac life support (ACLS) protocols, as proscribed by the American Heart Association (AHA), should be followed when treating all cardiac derangements caused by MH.

## General Equipment

) Syringes (60 mL × 5) to dilute dantrolene
) Mini-spike IV additive pins × 2 and Multi-Ad fluid transfer sets × 2 (to reconstitute dantrolene). Call MHAUS for ordering info
) Angiocaths: 16G, 18G, 20G, 2-in; 22G, 1-in; 24G, ¾-in (four each) for IV access and arterial line
) Nasogastric (NG) tubes: sizes appropriate for your patient population

) Blood pump.
) Irrigation tray with piston syringe (×1) for NG irrigation.
') Toomey irrigation syringes (60 mL ×2) for NG irrigation.
) Microdrip IV set (×1).

## Monitoring Equipment

) Esophageal or other core temperature probes
) Central venous pressure (CVP) kits (sizes appropriate for your patient population)
) Transducer kits for arterial and central venous cannulation

## Nursing Supplies

) A minimum of 3,000 mL of refrigerated cold saline solution
) Large sterile Steri-Drape (for rapid drape of wound)
) Three-way irrigating Foley catheters (sizes appropriate for your patient population).
) Urine meter × 1.
) Irrigation tray with piston syringe.
) Large clear plastic bags for ice × 4.
') Small plastic bags for ice × 4.
) Bucket for ice.

## Laboratory Testing Supplies

) Syringes (3 mL) for blood gas analysis for ABG kits × 6.
) Blood specimen tubes (each test should have 2 pediatric and 2 large tubes): (A) for CK, myoglobin, SMA 19 (LDH, electrolytes, thyroid studies); (B) for PT/PTT, fibrinogen, fibrin split products; (C) complete blood count (CBC), platelets; (D) blood gas syringe (lactic acid level).
) Urine-collection container for myoglobin level. Pigmenturia indicates that renal protection is mandated; unless the centrifuged or settled sample shows supernatant, i.e., the coloration is due to ret cells in the sample.
) Urine dipstick: hemoglobin.

## Forms

) Laboratory request forms: ABG form × 6; hematology form × 2; chemistry form × 2; coagulation form × 2; urinalysis form × 2; physician order form × 2.
) Adverse Metabolic Reaction to Anesthesia (AMRA) Report form (obtained from MH Registry).
) Consult form, if needed, for requesting a consultation from another physician.

## Preparing the Anesthesia Machine for MH-Susceptible Patients

- Ensure that vaporizers are disabled by removing, draining, or taping in the "OFF" position.
- Some consultants recommend changing the $CO_2$ absorbent.
- Flow 15 L/min $O_2$ through circuits via ventilator for at least 20 to 40 minutes. Given differences in design and manufacturing, consider checking the manufacturer recommendations for minimal washout times.
- Place new, disposable breathing circuit and breathing bag.
- Use expired-gas analyzer to confirm absence of volatile gases.
- Consider removing succinylcholine from the operating room, especially if there will be a change of personnel (i.e., for breaks or end-of-day relief).

## Contact Information

- MH Hotline: 1-800-644-9737 or 1-315-464-7079 (outside US).
- North American MH Registry of MHAUS registers information about specific families and patients. Registry is located at Children's Hospital at the University of Pittsburgh. See www.mhreg.org or call 1-888-274-7899.
- MHAUS provides educational and technical information to patients and health care providers at www.mhaus.org. They generally do not register cases in other countries, but do field calls from all over the world.

### TAKE HOME POINTS

- As above!

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# Good Old-Fashioned Basic Perioperative Blood Pressure Control

Edwin G. Avery IV, MD and Brian K. Johnson, MD MEd

A 66-year-old male with severe claudication, peripheral arterial vascular disease, hypertension, chronic renal insufficiency (glomerular filtration rate 27), dyslipidemia, diabetes mellitus type II, and chronic low back pain presents for elective bilateral lower-extremity arterial angiography with likely balloon angioplasty and stenting planned. His chronic back pain obviates his ability to lie still with a conscious sedation-based anesthetic. Once safely induced into general anesthesia with the airway secured, his blood pressure is noted to be 141/65 mm Hg, heart rate 67 beats per minute (sinus rhythm) and $SpO_2$ 99% ($F_iO_2$ 0.4). His preoperative blood pressure was 172/89 mm Hg and he had taken all of his antihypertensive medications as directed on the morning of surgery. Where should you keep the blood pressure for him and what are you concerned with if his BP runs either too high, too low, or both during the procedure?

## Blood Pressure Control in the 21st Century

We spent a considerable amount of time developing this chapter of the book. Emails and discussion points went back and forth as we debated the practices at our respective institutions as well as our individual predictions for the future standards of perioperative blood pressure management. We did not come to a complete consensus on every point! But we did come to joke among ourselves that managing perioperative blood pressure is like making the basic lasagna—a couple of simple ingredients make a dish that is deceptively more than the sum of its parts. Similarly, the basic "ingredients" of blood pressure are taught and learned pretty easily in medical school—the inotropic state of the heart, the state of the vasculature, and volume status, of course. But these physiologic factors can combine into perioperative management challenges that are deceptively more than you bargained for.

So anesthesiologists must guard against the mindset that blood pressure (BP) control is simple and straightforward. And we must ask ourselves—do we have a **true**

understanding of what BP goals are appropriate perioperatively? And are we as routinely successful as we would like to be in managing a patient's BP? We all have those roller-coaster days of blood pressure lability and we all intensely dislike and are frustrated by them; so the authors think perhaps not. In most cases, we continue to use slightly more advanced but still basic principles from our basic science physiology classes to determine an individual patient's ideal BP range in the perioperative setting. For example, we aim for a mean arterial pressure (MAP) of 70 mm Hg, or MAP of 50 mm Hg to 150 mm Hg to remain within the cerebral autoregulatory range, or the baseline BP on day of surgery or 20% lower than baseline BP if the patient is hypertensive. But we now know that these basic concepts of perioperative blood pressure control are just the basics. We also now have a significant body of peer-reviewed literature that supports the concept that poor perioperative BP control, even for just a handful of hours in the operating room, can have a significant impact on postoperative morbidity and mortality, including neurocognitive dysfunction, renal injury, myocardial infarction, and stroke. In addition, goal-directed therapy (aka enhanced surgical recovery) in almost all varieties of surgical patients is in fact a multidimensional concept with effective blood pressure management being just one important aspect of optimizing perioperative care. So we must not become complacent in our belief that BP management is a ho-hum and easy-peasy topic, because it most definitely is not.

## It's a Big World but Here is BP Management That Should Work for Everyone

Even if you are fortunate enough to get a vigilant patient with a diagnosis of hypertension who presents you with spreadsheets of daily blood pressure readings with accompanying multicolored graphs and a detailed medications list (and don't hold your breath waiting for a patient like this to wander into your OR), you have to consider that the challenge of determining an optimal perioperative BP range is still not so simple. General anesthesia is accompanied by various degrees of sympathectomy as well as frequent temperature, acid–base, and intravascular volume dynamics which are encountered in more complex surgeries that will challenge the effectiveness of the body's autoregulatory mechanisms and reflex physiologic responses. In a patient with limited organ reserve, such as our vasculopath presented in the vignette with shoddy kidneys, we certainly don't want to make his renal function, or any other organ function for that matter any worse. As discussed above, poor perioperative BP control has been strongly linked to increased perioperative morbidity and mortality and it is for these reasons that we personally advocate for the use of advanced parameter monitoring in patients with limited organ reserve, as we discuss in more depth in Chapter 137.

However … what should you actually **do**? Not every institution and/or anesthesia department has the same access and availability with respect to equipment, not to mention the same clinical practices, expertise, analysis, opinions, and ICU management philosophies. And to make matters even more confusing, review of the published literature on perioperative blood pressure control is full of conflicting information. But you have to do something—you have a patient in front of you, he's going to have an internal cardiovascular state and organ perfusion status, one way or the other. And you sure do want to control the blood pressure, because you don't want the blood pressure to control you.

So, we finally decided to put our collective experiences together and craft an approach for you to strongly consider while pondering BP management for a patient like our vignette patient. These recommendations should work for a variety of clinicians in a variety of settings:

) In patients that have a systolic blood pressure greater than 180 mm Hg and/or diastolic pressure greater than 120 mm Hg with clear evidence of end-organ damage (e.g., myocardial ischemia, acute congestive heart failure, new evidence of acute kidney injury, changes in vision, new cerebral pathology), this is the definition of a hypertensive emergency and the nonemergent case should be cancelled with immediate referral of the patient to inpatient treatment.

) In patients with the same blood pressure detailed in point #1 without clear evidence of end-organ damage, this is the definition of a hypertensive urgency (if anxiolysis does not improve the blood pressure). These patients should have their systolic or mean arterial pressure slowly lowered by 20% to 25% (over 30 to 60 minutes) and maintain this goal perioperatively while closely monitoring for signs and symptoms of neuroischemia.

) In hypertensive patients that do not meet the hypertensive emergency/urgency criteria (i.e., those with systolic blood pressure greater than 140 mm Hg and/or diastolic blood pressure greater than 80 mm Hg), lower the systolic pressure by 20% and maintain that goal perioperatively.

Finally, there are certainly many patients that we provide care for that are younger, possess sufficient organ reserve function and undergo elective noncomplex surgery with minimal fluid shifts (e.g., knee arthroscopy), and present with only relatively mild increases in blood pressure. In such cases more involved monitoring modalities can be foregone and patients can be managed with more contemporary enhanced surgical recovery techniques that include permitting the patient to drink clear carbohydrate-containing beverages up to 2 hours prior to surgery, use of multimodal analgesics to reduce narcotic dosing, and early use of the gastrointestinal tract (i.e., feed patients a

light meal in the postanesthesia care unit). Consider that intravascular volume contraction related to NPO guidelines can result in significant systemic arterial vasoconstriction with accompanying observed hypertension and these patients may respond favorably to cautious IV fluid replacement therapy. Those that fail to respond to volume expansion can be managed with the approach detailed in point #3 above.

## TAKE HOME POINTS

- Perioperative hypertension is a common problem for anesthesia clinicians and recent literature suggests that mismanagement for even a few hours around the time of surgery can have significant physiologic/outcome consequences (e.g., watershed stroke or myocardial ischemia).
- Merely targeting a mean arterial pressure of greater than or equal to 70 mm Hg may not be an acceptable strategy to manage perioperative hypertension.
- Individuals presenting for elective surgery with a hypertensive emergency as defined in the first point above should have their surgery cancelled and be referred for inpatient treatment.
- Adequately anxiolysed individuals presenting for surgery with a hypertensive urgency or less severe hypertension as detailed in the second and third points should have their systolic blood pressure lowered by approximately 20% through either volume expansion in those suspected of significant volume contraction or administration of antihypertensives.

## Suggested Readings


Ameloot K, Palmers PJ, Malbrain ML. The accuracy of noninvasive cardiac output and pressure measurements with finger cuff: A concise review. Curr Opin Crit Care. 2015;21(3):232–239.

Aronson S, Dyke CM, Levy JH, et al. Does perioperative systolic blood pressure variability predict mortality after cardiac surgery? An exploratory analysis of the ECLIPSE trials. Anes Analg. 2011;113(1):19–30.

Ono M, Brady K, Easley B, et al. Duration and magnitude of blood pressure below cerebral autoregulation threshold during cardiopulmonary bypass is associated with major organ morbidity and operative mortality. J Thorac Cardiovasc Surg. 2014;147(1):483–489.

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# 137

# Some Additional Thoughts on Blood Pressure Management Techniques—What We Believe, How We Do It, and Where We Think the Science Is Going

Edwin G. Avery IV, MD and Brian K. Johnson, MD MEd

In Chapter 136, we reviewed the fundamental principles and targets of perioperative blood pressure (BP) control. But here's the thing: the world of patient care is a big place with a wide range of clinical practices, expertise, analysis, and opinions. In our lively editorial debate, it became apparent that not every institution has the same access and availability with respect to equipment. Institutions that have the same equipment use it differently at their respective locations. Anesthesiologists within the same institutions and in different subspecialties vary in their opinions and practices. Practitioners evolve their practices and then evolve them back. And postoperative ICU management philosophies vary, of course, which has a ripple effect on patient management backward through the perioperative timeline.

At the authors' institution, the cerebral oximeter used together with the noninvasive oscillatory/near infra-red BP technology provides the best way to maintain vital organ perfusion in the perioperative setting—and all without poking any extra holes in the patient. We are certainly aware that there are numerous clinicians who do not have or use these technologies for blood pressure management and these folks rely on the traditional metrics discussed in Chapter 136, such as targeting baseline mean/systolic/diastolic arterial pressure, absence of tachycardia, moistness of mucous membranes, and observed urine output to determine if the vital organs are adequately perfused and if volume status is optimal. However, in our clinical practice and academic work, we are focused on moving past the traditional metrics toward developing and promoting the precision metrics. Our tagline among ourselves in our corner of the world is: when these two distinct approaches of perioperative BP management are compared it's like the Flintstones meet the Jetsons …

The patient in the vignette in Chapter 136 was a 66-year-old man with hypertension,

diabetes, vascular disease, and diabetes. **How would we personally manage this patient?** Our anesthetic plan for this challenging but common clinical situation would involve the use of a cerebral oximeter and a noninvasive blood pressure monitor that can provide beat-to-beat BP data as well as cardiac performance data. We feel the cerebral oximeter has supreme utility in protecting the brain's oxygen balance as has been demonstrated by multiple randomized controlled trials and observational studies (discussed below), in that there is significantly lower incidence of postoperative neurocognitive dysfunction in a variety of surgical settings. Think of the brain like "the canary in the coal mine" because if you protect the brain's oxygen balance the rest of the organs should be OK since the brain uses proportionally more oxygen and has limited reserve to tolerate ischemia. During a general anesthetic, the brain should have a lower cerebral metabolic rate and if it is extracting more oxygen while the patient is asleep, as opposed to when the patient is awake and doing mental long division in their head, it should not be increasing its oxygen extraction. The cerebral oximeter tells you when there is increased oxygen extraction in the brain by revealing a decrease below the patient's baseline regional saturation ($rSO_2$) values (N.B. less than 15% to 20% below the established baseline is considered a significant desaturation and less than 25% is a critical desaturation). A decrease in cerebral oxygen saturation most commonly heralds a decrease in oxygen delivery for any number of reasons—hypotension or relative hypotension below the lower limit of cerebral autoregulation is just one possibility, while others may include hypoxia, hypocarbia, hypovolemia, low cardiac output, and anemia.

The cerebral oximeter is effectively a poor man's way to determine the lower limit of cerebral autoregulation which has been well demonstrated to be a moving target during general anesthesia. For example, if a patient's mean arterial pressure (MAP) is 80 mm Hg at baseline and during anesthesia you keep the MAP at 80 mm Hg but see a bilateral cerebral desaturation of 15% to 20% or more below the patient's baseline then you know there is decrease in oxygen delivery to the head. If raising the MAP to 90 mm Hg resolves the desaturation then we know the patient's cerebral blood flow was pressure passive and the patient was below the lower limit of cerebral autoregulation. We can do all this noninvasively with two adhesive near-infrared sensor pads applied to the patient's forehead in lieu of complex and cumbersome transcranial Doppler monitoring; the use of cerebral oximetry in this capacity is well-validated in the peer-reviewed literature.

While the cerebral oximeter is a great tool for determining vital organ perfusion and maintaining oxygen balance, we should also consider another noninvasive option such as the ClearSight® device (Edwards Lifesciences, Irvine, CA). This noninvasive finger BP cuff uses a combination of near-infrared technology and oscillatory manipulation of

the finger arteries to produce a beat-to-beat arterial waveform as obtained with an arterial catheter. Shortly after, in about 10 seconds or so, analysis of the constructed arterial waveform, the device will also produce accurate cardiac index/output, stroke volume, stroke volume variation, and systemic vascular resistance parameters under most clinical conditions. Furthermore, these cardiac performance parameters are updated several times each minute giving clinicians the most up-to-date hemodynamic information on a continuous basis. Appropriate use of these parameters not only permits maintenance of adequate tissue oxygen delivery but also a means by which to provide optimal fluid management in the perioperative setting—another clinical area that we frequently score low marks in during the perioperative period. It is well documented that both underresuscitation and fluid-overload may result in an increased rate of perioperative complications that are proven to have significant economic consequences.

The management of perioperative hypertension remains a challenge to clinicians and approaches will vary until additional large-scale randomized controlled trials are conducted to help guide therapies. That said, a number of studies that we feel are important are discussed in the Take Home Points below.

Finally, the unconvinced reader should review the studies cited below that demonstrate how the cerebral oximeter can accurately find the lower limit of cerebral autoregulation in the majority of patients undergoing cardiac surgery as well as work on the clinical impact (i.e., acute kidney injury and increased mortality) of having cardiac surgical patients below the lower limit of cerebral autoregulation.

**Disclosure:** Dr. Avery is an educational consultant to Medtronic on the topic of the clinical use of NIRS cerebral oximetry; he delivers both peer-to-peer education as well as speaker's bureau lectures for which he has accepted honoraria. Dr. Avery has received research funding support from Medtronic for an Investigator-initiated protocol evaluating the use of cerebral oximetry in thoracic surgery.

## TAKE HOME POINTS

- We feel the cerebral oximeter and an advanced hemodynamic parameter monitoring device finger cuff provides a novel approach to perioperative blood pressure management for clinicians with access to the equipment and technology.
- In our practice, this technique provides highly accurate blood pressure information as well as cardiac index and stroke volume index, and is likely the best way to find a safe blood pressure range in the perioperative period.
- Using the brain's frontal lobes as the "canary in the coal mine" can provide optimal end-organ protection for the body. Patients with cerebral desaturations of 15% to

20% or more below their established awake baselines that demonstrate pressure passive flow should have their mean arterial pressure raised (e.g., with intravascular volume expansion, vasoconstrictors, or inotropes) to reverse any observed cerebral desaturation.

- **And now a personal note from Dr. Avery :** First, I am completely aware that there are not enormous numbers of people using cerebral oximeters in the manner that our cardiac anesthesiologists do. Second, I feel strongly about making the appropriate upfront disclosures when discussing or debating pretty much any aspect of cerebral oximetry for which I have received direct or indirect compensation. That said, I feel that researching this technology, teaching about it, and using it in my practice (including frequently outside of cardiac surgery) has given me a unique perspective. I have a sincere belief in the use of cerebral oximetry and hope that the rest of the anesthesia world will soon catch up. I do recognize that this is not a universal opinion, at present. I have great respect for my colleagues who do not use this technology but also great respect for and confidence in my colleagues who were the early proponents of this technology and who believe that it has the ability to help find the lower limits of cerebral autoregulation without transcranial Doppler. As I began to use these techniques, it was then my own realization that even with the near infrared spectroscopy (NIRS) data you still need to know about flow to the organs and blood pressure if you want to get it right every time. I like to think of combining NIRS cerebral oximetry with an advanced parameter noninvasive hemodynamic monitor as the perfect cocktail to ensure both optimal end-organ perfusion and appropriate maintenance of intravascular volume status.
- In "Suggested Readings", we have included information on the prospective randomized controlled trials that demonstrate NIRS effectively reduced neurocognitive dysfunction in cardiac surgical patients. Neurocognitive dysfunction, of course, is a frequent complication of cardiac surgery and an expensive one. We also direct your attention to John Murkin's work that demonstrated reduced complications and reduced ICU length of stay in cardiac surgery patients. The Andrea Casati prospective, randomized, controlled trial paper covers major abdominal surgery and, in this study, mini-mental status examination scores were favorable in those randomized to open NIRS monitoring with an interventional algorithm. The Casati study also showed dramatic reduction in both PACU and hospital length-of-stay.

## Suggested Readings

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Ono M, Arnaoutakis G, Fine DM, et al. Blood pressure excursions below the cerebral autoregulation threshold during cardiac surgery are associated with acute kidney injury. Crit Care Med. 2013;41(2):464–471.
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# Protect the Kidneys, Not the "UOP"

Michael P. Hutchens, MD MA

It is axiomatic in anesthesiology that abundant, or at least physiologically normal, intraoperative urine output (UOP) is essential to a good postoperative renal outcome; and consensus guidelines state that intraoperative volume administration should be based on objective measures of hypovolemia and that fluid excess should be avoided because it is deleterious even without overt complications. Although it is still true that the best monitor of intraoperative renal function is UOP, this is unfortunately true only in the sense that there is no other monitor of even passable use. One should not confuse poor data from a bad monitor with excellent data (such as from end-tidal capnography) from a monitor that demands action. Urine output is often used as a measure of hypovolemia, but it is not necessarily objective. This chapter focuses on situations in which the anesthesia provider must be cautious in the use of oliguria as a sign of hypovolemia. Unfortunately, the differential diagnosis of intraoperative oliguria is not hypovolemia alone.

Aggressive volume resuscitation of a patient with intraoperative oliguria due to unsuspected acute kidney injury (from sepsis, cardiorenal syndrome, or perioperative nephrotoxins) without monitoring of central venous pressure may result in intravascular volume overload without correction of the oliguria. In these patients, volume resuscitation in excess of normal volume status can lead to heart failure and pulmonary edema also. Occasionally, large volumes of fluid are administered to a physiologically normal but oliguric patient in an attempt to correct presumed hypovolemia when in fact the problem is a kinked urinary catheter or an unsuspected urinary tract injury in the surgical field. In the first case, delayed diagnosis of the kinked catheter and volume resuscitation will result in an overdistended bladder and ultimately obstructive renal failure. In the second case, renal function may be unaffected.

It has been frequently observed that patients undergoing laparoscopic surgery have lower-than-expected intraoperative UOP. Aggressive volume resuscitation in these patients may or may not increase their UOP. Euvolemia or slight relative hypervolemia may be necessary to ensure adequate blood pressure in this setting (because of increased intrathoracic pressure reducing return to the right heart). **But does the**

**reduced UOP reflect a danger to the kidney?** Early laparoscopists thought this was the case—that pneumoperitoneum caused renal vein and parenchymal compression, which resulted in oliguria and eventually renal injury. There is now good evidence to show otherwise. In multiple studies in animal models, pneumoperitoneum of 15 mm Hg or less (the upper limit for most laparoscopic procedures is 15 mm Hg) predictably reduces UOP but does not result in significant changes in ultrasound, pathologic, or chemical indicators of renal function. This question has also been evaluated in humans. As laparoscopic gastric bypass was being developed, Nguyen et al. reported on renal physiology in more than 100 patients assigned randomly to either laparoscopic or open gastric bypass. Despite a longer operative time and 64% lower intraoperative UOP in the laparoscopic group, there was no significant difference in postoperative blood urea nitrogen (BUN), creatinine, antidiuretic hormone (ADH), aldosterone, or renin levels, strongly suggesting that the reduced UOP reflects a reversible noninjurious physiologic consequence of pneumoperitoneum.

Similarly, the development of the laparoscopic donor nephrectomy offered an opportunity to study the effect of pneumoperitoneum directly, in both the retained and the transplanted (hence stressed) kidney. Hawasli et al. studied the effect on donated and retained kidneys of two different levels of pneumoperitoneum (10 and 15 mm Hg). They found no difference in UOP or other indices of renal function between the groups. Importantly, the transplanted kidneys functioned equally well whether harvested at high or low pressure. Intraoperative UOP is generally controlled aggressively with fluids, hypervolemia, and diuretics during donor nephrectomy, so it is impossible to assess relative oliguria in this population, but studies have shown that the laparoscopic donor operation produces allograft function that is equivalent to that of the open operation.

Laparoscopic surgery is not the only setting in which relative oliguria may not be harmful. Patients undergoing radical head and neck surgery have also been observed to have relative oliguria intraoperatively. Priano et al. studied “dry” versus “wet” resuscitation strategies in head/neck surgery patients with normal preoperative renal function, finding that resuscitation of more than 1 L/hr produced a UOP of 1.3 mL/kg/hr; half-dose resuscitation was associated with significantly less UOP (0.4 mL/kg/hr). Both groups had normal intraoperative and postoperative hemodynamics, and normal postoperative renal function.

The anesthetic doctrine of “plentiful pee,” then, has important exceptions. This is the case because a “normal” UOP is a second-line surrogate marker for instantaneous renal function, analogous to depending on the surgeons’ assessment of blood color to measure adequacy of oxygenation. New technologies such as continuous renal ultrasound and near-infrared regional oximetry offer some hope of improving the monitoring of intraoperative renal function. In the meantime, we must use the monitor we have with

intelligence, sophistication, and a high level of skepticism.

## TAKE HOME POINTS

- Urine output is a poor monitor of renal function, but it's the only one we have in the operating room.
- Laparoscopic surgery patients can have low intraoperative UOP without detriment to postoperative renal function.
- Radical head and neck surgery patients can have low intraoperative UOP without detriment to postoperative renal function.

## Suggested Readings


Feldheiser A, Aziz O, Baldini C, et al. Enhanced recovery after surgery (ERAS) for gastrointestinal surgery, part 2: Consensus statement for anaesthesia practice. Acta Anesth Scand. 2015;60(3):289–334.

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# Avoid a 70% Mortality Rate: Do Everything You Can to Prevent Perioperative Renal Failure

Michael P. Hutchens, MD MA

Acute renal failure in the postoperative period is appallingly common and has abysmal outcomes. In high-risk populations the incidence may be as high as 25%, and patients who require critical care services and renal replacement therapy have repeatedly been shown to have a mortality rate >70%. Despite this, perioperative resuscitation strategies are frequently formed solely with cardiac and pulmonary outcomes in mind. An early extubation is a pyrrhic victory if it condemns the patient to a slow death or lifetime dialysis. Despite decades of research, the risk factors, etiology, prevention, and treatment of perioperative acute renal failure all remain murky. Numerous interventions have been assessed, with few promising results. There are a few tools at hand, though, and the devastating effect of acute renal failure obligates anesthesiologists to use the tools available with the best possible dexterity.

The most consistent risk factor for perioperative renal failure is preoperative renal dysfunction. Elevated creatinine or decreased creatinine clearance, or a preoperative diagnosis of renal insufficiency, all significantly increase the risk of postoperative renal failure. Preoperative heart failure and diabetes mellitus are also significant predictors, as are the acute comorbidities rhabdomyolysis, fulminant liver failure, abdominal compartment syndrome, and sepsis. Surgical procedures involving cardiopulmonary bypass or aortic cross-clamp (any aortic cross-clamp, not just suprarenal clamping) increase the risk as well. Perioperative diagnostic studies involving nephrotoxic radiocontrast and medical management of concurrent nonsurgical disease (chemotherapy, aminoglycosides, nonsteroidal anti-inflammatory drugs [NSAIDs]) can further elevate the risk.

Anesthetic management directed at preventing acute renal failure ranges from banal to complex. If possible, stop nephrotoxic medications preoperatively. Certainly do not give preoperative NSAIDs to improve analgesia in at-risk patients. For procedures that will take 2 hours or more, a Foley catheter should be placed. Ensure that urine enters

the Foley catheter when it is placed, as a misplaced Foley and subsequent obstruction can cause renal failure.

In current practice there is no longer a fixed "goal" for hourly urine output; the objective is to monitor urine output diligently, and if it drops, intervene—increase perfusion pressure, give a fluid challenge, and inform the surgeon. If need be, place a central venous pressure (CVP)— while this may not allow for the estimation of volume status or volume responsiveness, a high CVP (i.e., >8 mm Hg) may impede microcirculatory flow, especially in the kidney, and may need an intervention. Eschew nephrotoxic agents in your anesthetic plan—ketorolac, dextran or synthetic starches, and aminoglycosides—should be avoided. It is clear that hypoperfusion contributes to perioperative renal failure; in at-risk patients, maintaining perfusion pressure is a high priority. What does this mean? There is some evidence to support that MAPs should be maintained greater than 60 mm Hg in the normotensive patient. Patients with chronic hypertension, due to changes in renal autoregulation, may need even higher pressures. Have a low threshold for placing an intra-arterial monitoring line, and use vasoactive agents, if necessary, to treat hypotension.

No therapeutic agent has shown broad renal-protective effect in the perioperative setting. Although there is lasting enthusiasm for low-dose dopamine, extensive study has shown it to have no effect on need for dialysis or mortality. Use of dopamine predictably causes tachycardia, which may be deleterious in a patient with concurrent coronary artery disease and increases the incidence of perioperative atrial fibrillation. Mannitol is commonly used in aortic cross-clamp cases; however, evidence to support this use is slim at best. Mannitol has been shown to be effective in preventing acute renal failure when used properly during renal transplant procedures. Although furosemide is popularly used to increase urine output, there is 30 years of evidence that furosemide can cause acute renal failure, and its use in the hypoperfused patient in the operating room (OR) is anathema. Other agents that have been used as putative intraoperative renal protectants include atrial natriuretic peptides, N-acetylcysteine, and fenoldopam. All have shown benefits in small studies that have not been replicable in large studies, suggesting that each may have use in a confined population, but what population remains unclear. A tantalizing study by Gandhi et al. in 2005 showed a significant association between intraoperative hyperglycemia and postoperative renal failure (defined as a doubling of creatinine, a creatinine >2, or new requirement for dialysis) in cardiac surgical patients. As intensive insulin therapy in the intensive care unit (ICU) reduces the need for dialysis, and as diabetes mellitus is a known risk factor, this raises the possibility that intraoperative insulin treatment may be renoprotective.

## TAKE HOME POINTS

- Although the anesthesiologist may not see it happening in the OR, acute renal failure is an anesthetic outcome with gargantuan impact on patient morbidity and mortality. Remember that we can see only oliguric acute renal failure, because typically we don't check the BUN and creatinine.
- The alert anesthesiologist must consider renal outcome in the anesthetic plan. Recognize the patient who is at risk because of preoperative disease or medical interventions.
- Maintain adequate circulating volume and perfusion pressure, and at all costs avoid doing harm with nephrotoxic agents.
- Consider tight intraoperative glucose control with insulin in diabetic patients.
- Finally, if you are concerned that the patient may be at risk for postoperative renal failure, communicate this to the surgeons, because early recognition and intervention in the postoperative period may improve the outcome.

## Suggested Readings


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# 140

# Do Not Use Urine Output as an Indicator of Volume Status in Hypothermic Patients

Juan N. Pulido, MD and Daniel R. Brown, MD PhD FCCM

Hypothermia is a clinical entity defined as a core body temperature less than 35°C (95°F) and is classified in four stages depending on the temperature, symptomatology, and effect on specific organ physiology (Table 140.1).

All organs are ultimately affected by hypothermia, including the kidneys. The renal response to cold is rapid and varies with the different stages of hypothermia. Initially, peripheral vasoconstriction results in relative central hypervolemia producing an increase in urine output. This response, termed "cold diuresis," has been described even in patients with mild to moderate hypothermia. The etiology of this phenomenon is multifactorial and includes an initial increase in cardiac output and renal blood flow resulting from hypothermia-induced changes in vascular capacitance. Other important contributors are nonosmotic suppression of antidiuretic hormone (ADH) release by the hypothalamus and subsequent decreased renal tubular reabsorption. These responses usually begin as soon as the core body temperature reaches 35°C and become more pronounced until moderate hypothermia, when decreased renal blood flow and glomerular filtration rate (reduced 50% at 27°C to 30°C) may lead to acute kidney injury.

Even in the setting of a large diuresis (the urine is usually dilute, with osmolarity <300 mOsm/L and specific gravity <1.003), the kidneys are unable to handle nitrogenous waste because of tubular dysfunction. Although they are uncommon, electrolyte disturbances including hypernatremia, hyperchloremia, and hyperkalemia can occur and are more frequent as hypothermia progresses in duration and/or severity. "Cold diuresis" is exacerbated by ethanol ingestion and water submersion, which may coexist with hypothermia and can potentiate inappropriate diuresis by inhibiting ADH secretion.

**Table 140.1 ■ Stages of Hypothermia**

| Stage | Core Temperature, çC (çF) | Characteristics |
|---|---|---|
| Mild | 32 (89.6)–35 (95) | Increased metabolic rate, hypertension, tachycardia, shivering, cold diuresis, CNS hyperexcitability, coagulopathy |
| Moderate | 28 (82.4)–32 (89.6) | Decreased cardiac output, hypoventilation, CNS depression, atrial arrhythmias, ↓ $O_2$ consumption (~25–50%) |
| Severe | 22 (71.6)–28 (82.4) | Progressive hypotension and bradycardia, ventricular arrhythmias, VF, decreased CBF, areflexia, loss of bulbar reflexes, decreased $O_2$ consumption (<50% of baseline) |
| Profound | <22 (71.6) | Asystole, EEG burst suppression |

CBF, cerebral blood flow; CNS, central nervous system; EEG, electroencephalogram; VF, ventricular fibrillation.

It is important to understand the pathophysiology of this phenomenon when making clinical decisions regarding fluid management in hypothermic patients. The "cold diuresis" can be massive and generally creates a hypovolemic state that worsens with rewarming because of the reverse changes in vascular tone as core body temperature is raised. If it is overlooked or underappreciated, this phenomenon can exacerbate electrolyte disturbances, contribute to hypotension, and result in prerenal stress.

Intravascular volume status should be closely monitored to avoid complications of this "physiologically inappropriate" renal response. Initially, it should be assumed that the patient is significantly dehydrated. Frequent measurements of electrolytes and hematocrit will help guide fluid therapy and electrolyte replacement, and help monitor for dehydration. Central venous access should be considered to allow for safer electrolyte replacement and rapid-volume administration, though electrolyte abnormalities may increase cardiac irritability and arrhythmia risk during catheter placement. Invasive arterial blood pressure monitoring should also be considered to facilitate laboratory determinations and to evaluate fluid responsiveness.

## TAKE HOME POINTS

- The renal response to hypothermia ranges from inappropriate diuresis (cold diuresis) to acute kidney injury.
- Cold diuresis will occur even in patients with mild to moderate hypothermia.
- The etiology is multifactorial, including changes in central volume distribution, cardiac output, organ perfusion, and suppression of ADH.
- Cold diuresis is exacerbated by ethanol ingestion and water submersion.
- Assume that cold patients are dehydrated—if appropriate, consider central venous access and invasive arterial blood pressure monitoring.

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# Perioperative Hyperglycemia Is Associated With Poorer Clinical Outcomes so Consider Insulin Therapy for Both Diabetic and Nondiabetic Patients With Elevated Blood Glucose

Tim Lee, MD

Hyperglycemia in the perioperative period is clearly associated with adverse clinical outcomes, including higher incidences of surgical site infection, pneumonia, infections of intravascular devices, sepsis, acute renal failure, blood product transfusion, neurocognitive dysfunction after cardiac surgery, and mortality. The underlying mechanism of hyperglycemia causing poor clinical outcomes is thought to be mediated through a number of mechanisms: impaired neutrophil and monocyte function, endothelial cell dysfunction, production of interleukin-6 (IL-6) and tumor necrosis factor-alpha (TNF-α) by mononuclear cells, induction of platelet activity, and elevated levels of fibrinogen and von Willebrand factor. Insulin therapy increases nitric oxide levels, inhibits free fatty acids, and reduces levels of inflammatory cytokines, in addition to its effect on the glycemic state.

The anesthesia provider should be vigilant in perioperative glycemic management in both diabetic and nondiabetic patients. There are a number of society guideline recommendations on glycemic targets during the perioperative period. **Preoperatively, diabetic patients having elective surgery should have preoperative HgbA1C of less than 7% as evidenced in multiple retrospective studies across different patient populations.** In 2009, American Association of Clinical Endocrinologists (AACE) and the American Diabetes Association (ADA) recommended target blood glucose (BG) levels between 140 and 180 mg/dL in critically ill patients. For patients in non-ICU settings, AACE/ADA recommended a fasting BG of less than 140 mg/dL and a random BG of less than 180 mg/dL for patients treated with insulin. The Society for Ambulatory Anesthesia (SAMBA) recommends intraoperative BG levels less than 180 mg/dL while acknowledging that most investigations into intraoperative glycemic control are focused

on cardiac surgery patients. They also noted that the provider should consider other factors such as duration of surgery, invasiveness of surgical procedure, type of anesthetic technique, and expected time to resume oral intake and routine antidiabetic therapy as well.

To achieve those goals, the AACE/ADA recommended administering continuous IV insulin infusions to critically ill patients or patients undergoing major surgeries. On the other hand, SC rapid-acting insulin should be administered to noncritically ill patients and patients undergoing ambulatory surgery or procedures of short duration (less than 4 hour operating room time).

Typical infusion dosing is 1 U of regular insulin/mL crystalloid (mix 100 U of regular insulin in 100 mL of 0.9% saline) given with a piggyback solution. The lines should be flushed with 20 mL of insulin infusion to saturate the insulin-binding sites in the tubing. First check the baseline BG and then infuse at a fairly slow rate if the initial value is not in the target BG range. A simple calculation for starting insulin in the operating room is to divide the BG by 100 and then round to the nearest 0.5 U for both the bolus dose and the infusion rate. As for SC injections, a useful approach is the "rule of 1500" (for regular insulin), which provides the expected decrease in BG with each unit of insulin—1500 is divided by the total daily insulin dose to determine the expected decrease in BG level with 1 unit of insulin. For example, in a patient requiring 50 U of insulin daily, each unit of insulin would be expected to reduce the BG level by roughly 30 mg/dL (i.e., 1500/50). The BG level should be checked at least hourly until it is stable and within the desired range. Aiming for tight glucose control may increase the risk of hypoglycemia (less than 70 mg/dL); therefore, strict monitoring is mandatory.

## TAKE HOME POINTS

- Hyperglycemia in the perioperative period is associated with adverse events as demonstrated by outcome studies.
- The anesthesia provider is responsible for perioperative glycemic control.
- Insulin administration in the perioperative period has been shown to improve clinical outcomes.
- Consider initiating treatment for BG >180 mg/dL in both critically ill and noncritically ill patients with target maintenance range of 140 to 180 mg/dL.
- Currently, mainstay of glucose control involves the use of insulin infusions in critically ill patients or patients undergoing major surgeries.
- In non-ICU patients and patients in ambulatory settings, SC rapid-acting insulin is preferred.

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# Seven Ways to Treat Hyperkalemia in the Perioperative Period

Grace Chen, MD

Hyperkalemia means serum potassium is above 5 to 5.5 mmol/L. Hyperkalemia has few clinical manifestations. In awake patients, severe muscle weakness beginning with the lower extremities and progressing cephalad, usually sparing cranial nerves and respiratory muscles, is sometimes evident. In patients under general anesthesia, the primary abnormality manifests as electrocardiogram (EKG) changes starting with peaked T waves, shortened QT interval, and progressive lengthening of the PR interval and QRS duration. The P wave may disappear, and ultimately, wide-complex ventricular tachycardia presents, eventually progressing to ventricular standstill. Hyperkalemia may also cause a variety of heart blocks, including bundle branch block and atrioventricular (AV) blocks. The manifestations of hyperkalemia depend on the rate of potassium rise—they are better tolerated by patients with chronic hyperkalemia. EKG changes with hyperkalemia are affected by concomitant hypocalcemia, acidemia, and hyponatremia.

## Pathogenesis of Hyperkalemia

Although hyperkalemia has many etiologies (Table 142.1), there are three distinct pathways: (1) ineffective elimination of potassium during any interval in the perioperative period, almost always due to renal failure; (2) acute potassium load from a medication error or massive transfusion of stored blood; (3) movement of potassium ions from the intracellular space to the extracellular space. This last pathway can occur with the use of succinylcholine, especially for burn patients or paraplegic/quadraplegic patients. It can also be seen with changes in ventilation and/or acid–base status in patients on certain drug combinations (spironolactone/beta-blockers) or significant physiologic derangements such as diabetic ketoacidosis. At the cellular level, hyperkalemia interferes with neuromuscular transmission and thus produces skeletal and cardiac muscle abnormalities. Neuromuscular transmission depends on membrane excitability. Increased extracellular potassium depolarizes the cell membrane, making

the cell more excitable, and requiring less of a stimulus to generate an action potential. The hyperexcitability eventually inactivates sodium channels and leads to cardiac conduction abnormalities and muscle paralysis.

**Table 142.1 ■ Disorders That Cause Hyperkalemia**

| Disorders That Lead to Hyperkalemia Caused by Impaired Renal Excretion of Potassium | Disorders That Lead to Hyperkalemia Caused by Shift of Potassium Into the Extracellular Space |
|---|---|
| Acquired hyporeninemic hypoaldosteronism | Damage to tissue from rhabdomyolysis, burns, or trauma |
| Addison disease | |
| Congenital adrenal hyperplasia (recessive or autosomal dominant) | Familial hyperkalemic periodic paralysis |
| Mineralocorticoid deficiency | Hyperosmolar states (e.g., uncontrolled diabetes, glucose infusions) |
| Primary hypoaldosteronism of hyporeninemia | Insulin deficiency or resistance |
| Pseudohypoaldosteronism | Tumor lysis syndrome |
| Renal insufficiency or failure | |
| Systemic lupus erythematosus | |
| Type IV renal tubular acidosis | |

## Treatment of Hyperkalemia

A valuable resource is the Cochrane Database of Systematic Reviews, which has published recommendations for emergency interventions for hyperkalemia. Current evidence suggests that intravenous (IV) insulin and glucose combined with nebulized beta-adrenergic receptor agonists were more effective than each treatment alone.

## Calcium

Calcium stabilizes cardiac muscle and directly antagonizes the hyperexcitability induced by hyperkalemia. Calcium starts acting within minutes and can be used as an

infusion for over 2 to 3 minutes. The dose is 500 mg to 1 g and may be repeated after 5 minutes. Calcium should not be given with bicarbonate, as calcium carbonate will precipitate. Patients who are taking digitalis are more vulnerable to toxicity with hypercalcemia, so calcium should be used with great caution in these patients.

## Insulin and Glucose

Insulin drives potassium ions into the cell by enhancing the sodium/potassium ATPase pump in skeletal muscle. Ten units plus 50 mL of 50% glucose as a bolus, followed by a glucose infusion, had been found to be effective in decreasing serum potassium. Alternatively, 50 mL of 50% glucose may be given to rapidly induce hyperinsulinemia.

## Sodium Bicarbonate

Sodium bicarbonate raises the pH of serum and, via the $H^+/K^+$ exchanger, drives hydrogen-ion release from inside the cell. Potassium, in turn, moves into the cell to maintain electroneutrality and thus reduces serum potassium levels. Ngugi et al. demonstrated that bicarbonate infusion lowered serum potassium levels by 0.47 ± 0.31 mmol/L at 30 minutes and thereafter. In addition, bicarbonate appears to reduce serum potassium levels by an unknown mechanism. However, the only placebo-controlled study, by Allon, found that bicarbonate did not lower serum potassium levels compared to placebo.

## Beta-Adrenergic Agonists

Beta-adrenergic agonists are effective in reducing serum potassium levels by 30 minutes after administration. The effect appears to be dose-responsive. Allon et al. demonstrated that 20 mg of nebulized albuterol reduced serum potassium levels. There does not seem to be a significant difference in effect between IV-administered or inhaled albuterol. With either route of delivery, further reduction in serum potassium levels may be attained by readministration of albuterol at 120 minutes. Of note, epinephrine can be used for its mixed effects if $beta_2$-adrenergic agents are not available. However, α-receptor stimulation causes potassium release from cells, especially in patients with renal failure.

## Loop or Thiazide Diuretics

Loop diuretics induce diuresis through sodium excretion, in the process activating the Na/K exchanger and inducing potassium wasting. Loop diuretics may be effective in mild renal impairment because loop diuretics are high-ceiling diuretics, meaning they have dose-dependent effects. Administering furosemide IV produces effects that depend on the patient's renal function, prior furosemide exposure, and many intraoperative

factors such as hydration status. Therapy using diuretics to lower potassium should be guided by frequent serum chemistry measurements, patient symptoms, and expected potassium trend.

## Cation-Exchange Resin

Sodium polystyrene sulfonate, administered orally or as a retention enema, binds potassium and releases sodium in the gastrointestinal (GI) tract. The oral dose is 15 to 30 g in 20% sorbitol solution. Enema doses are usually 50 g mixed with 50 mL of 70% sorbitol plus 100 to 150 mL of tap water. One dose can potentially lower plasma potassium by 0.5 to 1 mg/L. Resin seems to be less effective in renal failure patients. The routes of administration and slow onset render resins less effective in the acute rescue of intraoperative hyperkalemia.

## Dialysis

Dialysis may be performed in the perioperative period (including in the operating room!) in the event that more conservative treatments fail, if the hyperkalemia is severe, or if the patient has such massive tissue injuries that conservative treatment cannot keep pace with the amount of potassium released from cells. More potassium may be removed with increasing blood flow during dialysis.

## Blood Products

Although blood products are not a treatment for hyperkalemia, in cases in which massive transfusion is ongoing, especially if there is a degree of renal insufficiency, the anesthesia provider should request that the blood bank send recently donated blood and/or "washed" packed red blood cells to try to reduce the levels of exogenously administered potassium.

### TAKE HOME POINTS

- Be aware of the situations in which hyperkalemia commonly occurs—succinylcholine "mishaps," crush injuries, reperfusion of transplanted organs or ischemic limbs, and patients on spironolactone and beta-blockers.
- Consider hyperkalemia if the patient develops a new bundle branch or AV block in the perioperative period.
- Calcium stabilizes cardiac muscle membranes, but it must be used cautiously in patients on digitalis.
- Other therapies use the $Na^+/K^+$ and $H^+/K^+$ exchangers to move potassium intracellularly.

- Ask the blood bank to send packed red cells <5 days "old" or washed units.
- For severe or refractory cases, dialysis may be warranted.

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# Laparoscopic Procedures: Managing the Risks and Physiologic Effects During Camera Placement, $CO_2$ Insufflation, and Vertical Positioning

Benjarat Changyaleket, MD, Jennifer A. DeCou, MD, and Randal O. Dull, MD PhD

Laparoscopic surgery presents challenging issues for the anesthesiologist. It is one of the few procedures in which the surgical "incision" has resulted in life-threatening events. This type of procedure also involves the administration of intra-abdominal $CO_2$ and often requires extremes in patient positioning (Trendelenburg, reverse Trendelenburg), both of which have wide-ranging physiologic sequelae. Careful preoperative evaluation to determine the suitability and the degree of abdominal insufflation and tilted positioning, as well as meticulous intraoperative management planning, is critical to ensure a successful and safe operative outcome for the patient.

Prior to surgical incision, the anesthesiologist should confirm the planned technique for initial entry into the abdomen. Surgical practice has tended to evolve away from the Veress needle technique, which involves picking up the skin on either side of the umbilicus and using a "blind" technique to first pass a needle followed by a trocar. This technique has resulted in the uncommon but devastating complications of aorta and bowel injury. Much more common today is the Hasson cannula technique, which involves a microlaparotomy and placement of the initial intra-abdominal blunt-tipped cannula under direct observation. Subsequent trocars are then placed under camera visualization after insufflation.

Observe the placement of the trocars personally. It is not necessarily true that several attempts to place trocars and/or failure to initially insufflate to a proper pressure means trouble, especially with the Hasson technique. The trocars have a "cocking" mechanism that allows the sharp point to protrude out of the sheath, and this may need to be reset if activated when the surgeon attempts to place the trocar through the layers of the abdominal wall. Also, there may be leakage around the Hasson cannula, and the surgeon may ask for Xeroform to wrap around the cannula to get a seal. In general, however,

placement of the trocars should go fairly smoothly without an excessive number of attempts.

Of course, it is the insufflation of the abdomen or pelvis with gas (usually $CO_2$) to improve visualization of the surgical field that results in the physiologic changes that are of interest to us. The high solubility of $CO_2$ allows rapid diffusion into the blood compartment and causes predictable changes in blood gas chemistries and hypercapnia. It must be remembered at all times that the physiologic effects of insufflation and the resulting hypercapnia are multisystemic and quite complex.

In addition, the vertical (head-down or head-up) positioning that allows the surgeon to maximize view of the operative field after abdominal insufflation also has significant physiologic consequences. Trendelenburg (head-down) position produces changes that affect the cardiovascular, respiratory, and cerebrovascular systems whereas reverse Trendelenburg (head-up) position has the opposing effects to these systems.

## Cardiovascular Effects

The cardiovascular effects of abdominal insufflation are most pronounced during and just after injection of $CO_2$. They require that a range of resuscitative drugs be available. Hypercarbia and the associated acidosis can cause direct cardiac depression and peripheral vasodilatation, which can lead to hypotension. However, hypercarbia can also promote a strong sympathetic reflex and increases plasma catecholamine levels that may offset this depressant activity. The result is hypercarbia with a hyperkinetic circulation causing tachycardia, increased cardiac output, increased contractility, and increased systemic blood pressure. These changes can increase myocardial $O_2$ demand, and patients with known or suspected coronary artery disease will require appropriate interventions.

**Arrhythmias are commonly encountered during laparoscopic procedures.** Hypercarbia, acidosis, and the associated increase in catecholamines may sensitize the myocardium and induce a variety of arrhythmias. Vagally-mediated reflexes caused by insufflation can induce a variety of bradyarrhythmias, including asystole. Lastly, increases in intra-abdominal pressure can inhibit venous return, resulting in decreased cardiac output and hypotension; adjustments to intravascular volume may be required to normalize venous return and maintain cardiac output.

Similarly, extreme reverse Trendelenburg may lead to venous pooling with resultant hypotension. In patients with hypovolemia or flow-limited lesions (aortic stenosis, coronary/cerebrovascular occlusive diseases), positional hypotension can lead to cerebral and myocardial ischemia. In patients with flow-limited lesions in the brain, an arterial line should be strongly considered and placed at the level of the circle of Willis (ear level) to monitor cerebral perfusion pressure. On the other hand, one often sees

severe hypertension following steep Trendelenburg as a result of increased filling of the heart, thereby increasing venous return, stroke volume, and blood pressure. Together with increased afterload from the abdominal insufflation, the increase in blood pressure is augmented and may not be well tolerated in those with pre-existing congestive heart failure as the increased afterload places a greater energy demand on the heart.

## Intracranial Effects

The intracranial effects of insufflation and steep Trendelenburg are the easiest to overlook, as it is extremely rare to have direct measurement of intracranial pressure (ICP) during laparoscopic surgery.

$CO_2$ is the primary regulator of cerebral blood flow through its effect of inducing cerebral vasodilatation. Cerebral blood flow increases linearly with changes in $P_{CO_2}$ between 20 mm Hg and 100 mm Hg. ICP is a function of brain mass, cerebrospinal fluid volume, and blood volume. Although the relationship between cerebral blood flow and ICP is complex, a general assumption should be that increases in $P_{CO_2}$ will increase ICP. In the absence of direct ICP monitoring, prudence suggests that any change in $CO_2$ above normal may increase ICP. It is not uncommon for a senior practitioner to hear the question, "How high can we let the $CO_2$ go?" A reasonable answer is that acceptable limits to the increase in $P_{CO_2}$ during laparoscopic procedures should be directly related to concerns regarding elevated ICP. Thus a patient who should be exposed to only moderate increases in ICP should undergo only moderate increases in $P_{CO_2}$.

Moreover, the prolonged steep Trendelenburg is known to induce cerebral hypertension and edema, and raise ICP. Reverse Trendelenburg has the opposite effects that may reduce ICP by improving cerebrospinal fluid and venous drainage of the head and neck. Those with intracranial lesions with associated risks of increased ICP may be poor candidates for steep Trendelenburg position.

## Pulmonary Effects

Insufflation of the abdomen is generally considered among the stronger indications for endotracheal intubation because the pulmonary changes that occur during $CO_2$ insufflation are usually related to increased intra-abdominal pressure. The upward displacement of the diaphragm can predispose to passive or active regurgitation, cause atelectasis, reduce functional residual capacity (FRC), create an intrapulmonary shunt, and produce ventilation/perfusion (V/Q) mismatching and hypoxemia. Higher $P_{CO_2}$ levels as the case progresses may also cause the resumption of spontaneous ventilation. To offset these changes, administration of higher doses of neuromuscular blockade, adjustments to the rate of mechanical ventilation, tidal volume, inspiratory flow rate,

and the implementation of lung volume recruitment efforts are all part of intraoperative management during laparoscopic procedures. In addition, the anesthesiologist must always be vigilant for increases in airway pressure caused by a pneumothorax, which can occur when laparoscopic procedures are performed close to the diaphragm (e.g., gastric fundoplication).

Steep Trendelenburg position potentiates the respiratory perturbations seen with abdominal insufflation by furthering the cephalad displacement of the diaphragm, exacerbating the V/Q mismatch, and worsening the risks of aspiration, all of which lead to hypoxemia. Endobronchial migration of the endotracheal tube and failed extubation are also more common in the head-down position. In fact, leaving a patient intubated postoperatively may be warranted after a prolonged steep Trendelenburg positioning.

## Soft Tissue Effects

It is common for patients to develop subcutaneous emphysema during long laparoscopic procedures. Because of the high solubility of $CO_2$, considerable quantities can accumulate within body tissues during long procedures. On an individual basis, consider carefully before extubating patients who have undergone extended laparoscopic procedures. The large majority of patients can be and are extubated at the end of the procedure, but there are several issues complicating extubation. Subcutaneous emphysema involving the head and neck can be ascertained by visual inspection or by palpation—the patient may have a "crackling" under the skin. This may require postoperative intubation to prevent airway obstruction and while tissue stores are removed. Be aware that subcutaneous emphysema can be a sign of pneumothorax. Additionally, elderly patients and/or those with pre-existing pulmonary disease may be unable to sustain the $P_{CO_2}$-induced high minute ventilation following extubation and are at higher risk for reintubation.

One final note regarding the management of the sequelae of insufflation and hypercapnia is that in patients with comorbidities, those with impaired $CO_2$ excretion capacity (e.g., patients with chronic obstructive pulmonary disease), and patients with acute cardiopulmonary disturbances, strongly consider an arterial line for hemodynamic and blood gas monitoring.

### TAKE HOME POINTS

- Personally observe placement of the trocar—make sure the surgeons are using the Hasson technique. We have seen thousands of uncomplicated trocar placements and we have also seen the surgeons accidentally poke the femoral vein and perforate the bowel. So always keep in mind that there are uncomplicated placements but never

"routine" placements of the trocar.

- The physiologic effects of insufflation and hypercapnia are complex and can result in significant sequelae in cardiovascular, intracranial, and pulmonary status.
- Check every patient for significant subcutaneous emphysema in the chest and neck—look for "crackling" under the skin. Subcutaneous emphysema can indicate a clinically significant pneumothorax or predict a failed extubation.
- Communication with the surgical team perioperatively regarding the physiologic effects of tilted position is key to ensuring effective and safe outcome of the surgery.

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# Could This Be Methemoglobinemia, Maybe?

Leena Mathew, MD, Philip Shin, MD, and Walter Chang, MD

A morbidly obese 39-year-old man was presented for an open gastric bypass surgery. He had a history of obstructive sleep apnea, requiring continuous positive airway pressure (CPAP) at night. He had no known allergies to medications. The anesthetic plan was to proceed with an awake fiber-optic intubation for general endotracheal anesthesia. He was given a treatment of aerosolized 4% lidocaine for 20 minutes before entering the operating room (OR). In the OR, Cetacaine (benzocaine 14%, tetracaine 2%, and butyl amino benzoate 2%) spray was applied to the posterior oropharynx.

A transtracheal block was performed using 3 mL of 2% lidocaine. An awake nasal fiber-optic intubation was completed without difficulty. Within 15 minutes of intubation, the patient's pulse oximetry registered a progressive decline to 90% on an $FiO_2$ of 100%. As the surgeon made the incision he commented that the blood on the field looked "dark like chocolate." When an arterial blood sample was taken, it was also noted to be dark chocolate-colored. A presumptive diagnosis of methemoglobinemia was entertained. The arterial blood sample was sent for blood gas analysis and methemoglobin (MHb) levels. Because of technical difficulties in the laboratory, there was a delay in processing the blood gas sample. At this point, the decision was made to treat empirically with methylene blue; accordingly, 70 mg of methylene blue diluted in 50 mL of normal saline was given intravenously over 10 minutes. After an initial drop in the pulse oximetry reading to 88%, the reading rose progressively to the high 90s. Ten minutes after the entire dose, pulse oximetry read steadily at 99% on 100% oxygen. The patient was extubated without difficulty at the end of the procedure and discharged to home several days later. The result of the MHb level, available on postoperative day 1, was 24.6%.

Anesthesiologists commonly use local anesthetics to anesthetize the airway and pharynx in preparation for awake fiber-optic intubations or endoscopies. A rare though potentially serious toxicity associated with the use of local anesthetics is MHbemia. Anesthesiologists should understand the pathophysiology, presentation, diagnosis, and

treatment of MHbemia to prevent and/or manage potential problems.

In the case above, the patient experienced an arterial desaturation to 90% on an $FiO_2$ of 100% oxygen. The differential diagnosis for a low pulse oximetry measurement ($SpO_2$) included: pulse oximetry artifact, hypoxemia, abnormal hemoglobin variants, sulfhemoglobinemia, and MHbemia. Pulse oximetry relies on measurement of absorbed light from two diodes, one emitting light at 660 nm (red) and another at 940 nm (near-infrared). It is well known that pulse oximetry is distorted by artifacts arising from motion, ambient light, poor perfusion, and injected dyes including indigo carmine and methylene blue.

Hypoxemia is the most critical cause for low $SpO_2$ and must be investigated urgently. Hypoxemia may result from hypoxia, hypoventilation, shunting, ventilation/perfusion mismatching, decreased partial pressure of oxygen in mixed venous blood, and rarely, diffusion abnormalities. Quickly ruling out these causes of a low $SpO_2$ is paramount to caring for any patient. In this case, the patient was ventilated manually with 100% $FiO_2$. The tube placement was verified to be correct with a fiber-optic scope, auscultation, and presence of end-tidal $CO_2$. The nasotracheal endotracheal tube was suctioned and the breathing circuit checked for kinks. New-onset diffusion abnormality was highly unlikely.

## Methemoglobinemia

Only after ruling out the most common and critical causes for a low $SpO_2$ should one consider the possibility of MHbemia as the cause. MHb is the oxidized form of hemoglobin in which the iron moiety of MHb is in a trivalent ($Fe^{3+}$) ferric state rather than a divalent ($Fe^{2+}$) ferrous state. MHb is unable to bind oxygen and thus reduces the oxygen-carrying capacity of blood. In addition, MHb shifts the oxygen dissociation curve to the left, thus impairing release of oxygen from the heme molecule to tissue. Significant levels of MHbemia can place patients in a state of functional anemia.

## Methemoglobin Formation and Reduction

Normally there is a steady-state equilibrium between the levels of hemoglobin and MHb. The auto-oxidation of hemoglobin to MHb occurs at a rate of 0.5% to 3% per day. Levels of MHb remain below 2% by a mechanism of constant reduction (addition of an electron). The primary mechanism of MHb reduction to ferrous hemoglobin is through the nicotinamide adenine dinucleotide (NADH)–cytochrome b5 reductase pathway. An alternate enzymatic pathway for the reduction of MHb is mediated by NADPH–MHb reductase. This pathway generates electrons from glucose-6-phosphate dehydrogenase (G-6-P-D) in the hexose monophosphate shunt, which requires

methylene blue and/or flavin to function. Other minor pathways that reduce MHb include ascorbic acid, reduced glutathione, reduced flavin, tetrahydropterin, cysteine, cysteamine, 3-hydroxyanthranilic acid, and 3-hydroxykynurenine.

## Causes of Methemoglobinemia

Significant MHbemia occurs when there is an imbalance between hemoglobin oxidation and reduction. The causes of MHbemia may be categorized as congenital or acquired. The rare congenital causes include hemoglobin M and cytochrome b5 deficiency.

Hemoglobin M is a variant of hemoglobin that has an amino acid substitution rendering it resistant to reduction. It is inherited in an autosomal dominant pattern. Patients with this form of hemoglobin usually present with a long-standing history of cyanosis and a positive family history.

NADH–cytochrome b5 reductase deficiency is the other congenital cause of MHbemia. Inheritance of this deficiency occurs following an autosomal recessive pattern. This deficiency is subdivided into Types 1 and 2. Type 1 NADH–cytochrome b5 reductase deficiency is limited to the soluble form in erythrocytes. Cyanosis is often the only symptom, and patients with this deficiency are not usually treated. Type 2 deficiency involves both the soluble and bound isoforms of the enzyme. As opposed to the Type 1 deficiency, patients with Type 2 deficiency may have severe progressive neurologic symptoms which are untreatable.

The acquired causes of MHbemia are more common than the congenital causes. Acquired causes mostly involve medication/drug administration. Drugs known to cause MHbemia include antimalarials (chloroquine, primaquine), nitrites or nitrates, nitroprusside, inhaled nitric oxide, sulfonamides, acetanilide, metoclopromide, phenacetin, phenytoin, probenecid, chlorates, phenazopyridine hydrochloride, and local anesthetics including prilocaine, benzocaine, and lidocaine.

## Signs and Symptoms

The most common sign of MHb is cyanosis. In addition, patients with MHbemia have been noted to have chocolate-brownish–colored blood. Our patient's blood was described as being such by the surgeon, and the anesthesia team observed "chocolate"-colored blood on obtaining the arterial blood gas.

## Diagnosis

The diagnosis of MHbemia requires co-oximetry. Co-oximeters are spectrophotometers able to emit at least four different wavelengths of light, thus allowing for the measurement of four hemoglobin species: hemoglobin, oxyhemoglobin,

carboxyhemoglobin, and MHb. An arterial blood gas sample should be drawn and sent to the laboratory specifically requesting co-oximetry for MHb levels.

## Treatment

Not everyone with MHbemia requires treatment. MHb levels <30% usually resolve spontaneously over 15 to 20 hours without serious consequences. Those patients with higher MHb levels or patients limited by symptoms of MHb may be treated with methylene blue. The recommended dosage of methylene blue is 1 mg/kg over 5 minutes, and the dose may be repeated in 1 hour if the first dose is not ineffective. Methylene blue accelerates the action of the NADPH–MHb reductase, which is the body's alternate pathway for MHb reduction.

Methylene blue acts as an electron acceptor of NADPH-dependent MHbemia reduction, which under normal circumstances does not have an electron acceptor. Because treatment with methylene blue depends on NADPH as an electron donator, there must be adequate levels of NADPH available via the G-6-P-D pathway. Therefore, methylene blue needs an intact pentose phosphate pathway to regenerate NADPH for effectiveness.

For this reason, methylene blue would not be the treatment of choice in patients with G-6-P-D deficiency. In fact, giving these patients methylene blue may increase levels of MHbemia and cause hemolysis, because high concentrations of methylene blue can act as an oxidant. In patients with a G-6-P-D deficiency, treatment is available through the administration of ascorbic acid and riboflavin. Finally, in refractory or life-threatening cases, exchange transfusion and the use of a hyperbaric oxygen chamber may be necessary to treat MHb.

### TAKE HOME POINTS

- Anesthesia providers should be aware of the complication of acquired MHbemia resulting from the use of local anesthetics.
- The topicalization of a patient's airway for fiber-optic intubation is an especially vulnerable time for both the development of local anesthetic toxicity and MHbemia. This has been corroborated by multiple case reports in the gastrointestinal literature of MHbemia secondary to Cetacaine® spray topicalization of oral mucosa for endoscopic gastroduodenoscopies.
- In addition, there have been case reports in the cardiology literature of MHbemia from Cetacaine® spray preparation of the oral mucosa for transesophageal echocardiogram.
- The early recognition and treatment of MHbemia in patients can prevent adverse

outcomes in these patients and avoid unnecessary interventions that may contribute to morbidity.

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# The Eye Room—Is It the Easiest of Days? Or the Hardest of Days? Regardless, Vigilance Is Key!

David Larsen, MD and Ryan J. Fink, MD

An anesthesiologist may never be so involved or so bored as when they are performing an anesthetic for eye surgery. It can be very difficult, or one of the easiest anesthetics they will perform. Vigilance throughout the entire perioperative course is paramount for success!

There are a wide range of surgical procedures performed in or around the eye. Each with their own set of risks and problems to be considered when choosing an anesthetic, of course. Individual patients also have their own set of medical problems which further complicate the plan. Perhaps in no other arena is good communication between surgeon, patient, and anesthesiologist as important for patient satisfaction, patient safety, and surgical success as in ophthalmic surgery.

## Managing Expectations

When a patient is first informed they will need a surgery, one of the initial inquiries is how it will be done? At this initial moment, the surgeon sets the tone for the success of the anesthetic. Unfortunately, in this era of rapid clinical encounters there is not much time for the surgeon to fully discuss the anesthetic. Preferably the answer is a reassurance that the patient will be comfortable and should not feel any pain. When the surgeon knows the patient could be done under monitored anesthesia care (MAC), this should be relayed to the patient so he knows at the start that he will not be receiving a general anesthetic. Most eye centers even have short videos explaining the surgical procedure, with the accompanying anesthetic plan for their patients. Patients who view these are reassured they are no different, that their case is normal, and this is the way it has been done many times before**. At no time should the patient be told they will not remember anything.** This only sets the anesthesiologist up for failure and primes the patient to be very disappointed in their surgical experience.

Of course, gone are the days of the patient seeing their primary care doctor to give

"clearance" for surgery. Today, most centers have their own trained preoperative staff who help collate and collect the data necessary for the anesthesiologist to make sound decisions regarding their patient's care. These preop visits, whether by phone or by in-person visit, provide an invaluable opportunity for the patient to further discuss what to expect on their surgical date. Here, the patient is reminded of NPO status and the need to have an adult present to accompany them safely home. Here, the patient is reassured by the process, feels connected, and part of a system that cares about their surgical success and satisfaction. Finally, the patient receives another brief description of the scheduled anesthetic and what to expect.

On the day of surgery, the patient arrives and finally is able to speak with their anesthesiologist. At this encounter, the provider is doing more than just collecting data from the patient for their anesthesia assessment. They are sizing the patient up. Will this patient be able to tolerate lying flat for the procedure? Will this patient be able to stay still? Will this patient cause any trouble during the anesthetic? If there is any question from what the surgeon has initially scheduled to what the impression of the anesthesiologist would do for the anesthetic, a discussion should take place as to how best to proceed. When the plan is for a MAC anesthetic, the patient should be informed they will be awake and may hear their surgeon talking and perhaps some light music in the background. They may feel their eye move or slight pressure, but at no time should the patient feel pain. If they do, they are to immediately notify the surgeon and anesthesiologist. Together they will take steps to help the patient feel comfortable. **One of the most common errors made by anesthesiologists in the eye arena is not informing their patients that they will be awake and alert for their procedure.**

## Types of Anesthesia

### Topical

Cataracts are by far the most common procedure to be performed under a topical anesthetic. In fact, they are now being done in the office setting for cooperative patients. The surgeon places a couple of drops of anesthetic on the eye and is able to perform the procedure with the patient comfortable and wide awake. Should the patient ever feel any discomfort, the surgeon may place additional anesthetic on the eye, place a subconjunctival injection of local anesthetic, or perform a regional block. The anesthesiologist, in concert with the surgeon, may give the patient some intravenous anxiolytic and/or some opioid to help. It should not be the goal to sedate the patient so heavily they are then unable to cooperate. A cooperative patient is able to assist the surgeon by looking in a direction on request, thus helping the surgeon and themselves with a successful outcome. At any time it may be necessary to urgently switch to a general anesthetic. This contingency plan should be discussed and all items readily

available should be required. Other surgical procedures may be performed under topical anesthetic, although are less common.

Vigilance during topical anesthetics is important as it only takes a moment for something to change and requires the anesthesiologist to intervene. Something as simple as holding the patient's hand goes a long way to making a patient feel comfortable and well cared for.

## Regional Blocks

Typically these anesthetic blocks are performed by the surgeon as they have the training to correct complications which may occur, although in some centers anesthesia staff have received the necessary training. The well-known retrobulbar block has been utilized frequently as it achieves excellent surgical anesthesia and provides akinesia to the globe. Today, other types of blocks are becoming more popular as some feel they carry less risk to the patient. Notable among these is the sub-tenon's block. It is felt to have less risk of retrobulbar hemorrhage and less chance of the anesthetic accessing the central nervous system (CNS). It does not however, reliably give akinesia to the eye or prevent the patient from squeezing their eyelids during the surgery.

To provide for patient satisfaction and more stable conditions to give the block, many surgeons request sedation for the patient prior to block placement. Methods of sedation vary from one center to another. Some utilize small doses of methohexital, others utilize benzodiazepines only, and some combine the benzodiazepine with some short-acting opioid. **Be aware of giving propofol without other sedatives as it has been associated with the patient sneezing during block placement when it is solely given.**

Once the block has been administered, the patient is allowed to become more aware and cooperative prior to surgery starting. At some point, the patient will be fully aware, however, since the block has been placed should not experience any discomfort. Should the patient have pain, both the surgeon and the anesthesiologist would need to take steps to alleviate it.

A common problem with patients having their eye numb to surgical stimuli, but still aware of ambient stimuli, is the patient constantly talking. When the patient is talking, the surgeon is not concentrating and the patient's head is moving. Discussing the need for the patient not to talk about unnecessary things during the surgery, except to notify the team of discomfort, is invaluable to a satisfactory surgical experience.

Forgetting the patient is awake and allowing conversations from those in the room to wander inappropriately can lead to a problem as well. Remember to remind those in the room the patient is awake. Having the surgeon occasionally inquire how the patient is doing does a few beneficial things other than ensure patient comfort. First, it reminds the

patient that they are awake by design. Second, it reminds those in the room to watch their conversations. Third, it allows the inquiry to take place at a time when patient response will not disturb the surgeon's efforts.

## General Anesthetics

Not so long ago, almost all eye surgeries were done under a general anesthetic. Today, more and more surgeries are being performed as a block with the patient awake. The reasoning behind this shift in clinical practice varies from having more advanced surgical techniques, better surgeon comfort with patients being awake, or patients being more aware of the techniques utilized on others they know who did well. Whatever the cause, anesthesiologists must still prepare to do a general anesthetic in the arena of eye surgery.

Why are general anesthetics avoided? Mostly, it is for patient satisfaction. Patients tend to feel better and are more satisfied when their surgery can take place without the invasiveness of a general anesthetic. Afterward, they are less groggy, less nauseated, able to eat a good meal, and much more apt to return to their daily routine faster. Surgeons typically prefer to avoid general anesthetics in order to avoid increasing the time both before incision and after closure for their operating rooms. In addition, they do not want their patient to wretch, thus greatly increasing both the pressure on the eye and the likelihood of complications after surgery. Eye surgeries today tend to occur in outpatient surgical centers where rapid turnovers and high patient satisfaction are paramount. Because of this, a majority of eye surgeries are done as MAC/block anesthetics.

The location of the surgery is important to consider when choosing your anesthetic. If the patient is having their procedure in a tertiary care hospital then almost all patients can be considered candidates. However, if the patient is having their surgery in an outpatient surgical center, one must choose wisely those rendered as a general anesthetic. Although eye surgeries are low risk overall, some patients by virtue of their medical problems and physiology incur an untoward level of risk for themselves and their eye center. For this reason, it is recommended patients be screened for appropriateness of their anesthetic plan prior to the surgery date. For example, is it wise to perform a general anesthetic on an oxygen-dependent patient in your center if you do not have postoperative ventilation available? Each eye center must decide their own capabilities in appropriately caring for their patients.

If a patient is determined as a poor candidate for MAC anesthesia and a general anesthetic is determined the safest route possible for a good outcome, the anesthesiologist must then decide to utilize an endotracheal tube or a supraglottic airway for the surgery. On one hand, an endotracheal tube secures the airway nicely

allowing use of paralytic and higher positive airway pressures if needed. On the other hand, a supraglottic airway decreases the strain, and thus the intraocular pressure (IOP), put on the patient during airway placement as well as at emergence. Consider a patient who is having retinal surgery under general anesthetic. If, after much effort on the part of the surgeon, the patient emerges coughing on an endotracheal tube, the risk of intraocular hemorrhage increases, whereas the cough would be greatly minimized by the use of a supraglottic airway. This is why many eye centers utilize supraglottic airways in greater proportion than one would anticipate.

## Postoperative Course

After the surgery is complete and the patient is sitting upright getting ready to go home, a quick visit by the anesthesiologist helps in patient satisfaction. A quick hello, assessment of how things went, and a positive comment help the patient realize the smooth nature of what just transpired. It is an amazing thing to have had an eye surgery without pain or nausea and feel good enough to eat minutes later.

## Vigilance

No matter the anesthetic plan chosen, vigilance is key. The patient's satisfaction regarding their surgery starts the day they enter the surgeon's office for their consultation. What is said then matters greatly in how patients perceive the success of their surgery. Having all pertinent data collected and presented succinctly allows the anesthesiologist to formulate a plan such that the surgeon is able to perform a safe surgery and the patient has the best possible overall outcome. Most eye surgeries can be done without rendering the patient completely unconscious which in turn leads to better patient outcomes and satisfaction. If however, general anesthesia is necessary, one must think of the ramifications of the general anesthetic and minimize if possible potential pitfalls.

## Other Considerations for Eye Surgery

When a patient presents with a ruptured globe, it has been dogma to avoid succinylcholine as it raises the IOP which in turn could lead to further extrusion of intraocular contents. However, **consider the entire patient in your efforts to treat him or her**. It may be more beneficial to utilize succinylcholine and have the IOP increase by 5 to 12 mm Hg for a few minutes than to face a prolonged intubation due to a high dose of a nondepolarizing neuromuscular blocker. Or, in a patient who may be a difficult intubation and difficult mask and whose globe is completely deflated, it may be the wisest choice to use succinylcholine. Thankfully, with newer medications, the rapid

and safe reversal of paralysis from nondepolarizing neuromuscular blockers further decreases the need for succinylcholine.

If you do choose to utilize a nondepolarizing neuromuscular blocker, please allow sufficient time for it to actually block the receptors. The good intentions in avoiding succinylcholine could be wiped out by the patient coughing, thus increasing their IOP by 50 mm Hg or more.

Remember, retrobulbar blocks carry risks. These include puncturing the globe itself, causing a retrobulbar hematoma, or having the local anesthetic enter the CNS. The anesthesiologist can do little for the first two. However, should the block enter the CNS it becomes the purview of the anesthesiologist to ensure adequate cardiopulmonary function. It may be necessary to act quickly and secure an airway and treat any rhythm or blood pressure derangements. In addition during a retrobulbar block, the patient may have an episode of bradycardia due to the oculocardiac reflex. Thankfully, this is almost always short-lived with nothing to be done, except to release traction on the eye. However, anesthesiologists must be watchful and ready to act when needed.

Remember, a patient who has had a vitrectomy in the past may have had gas placed in their eye as part of their treatment. Giving these patients nitrous oxide is contraindicated as it greatly expands the gas space and increases the IOP to a point of no perfusion to the retina. If the anesthesia provider is unsure of the status of gas placement, then either a discussion should be held with the surgeon regarding this possibility or the anesthesiologist completely avoids nitrous oxide.

When a patient has her face covered during surgery and they are awake, they need fresh air flow. The anesthesiologist should ask himself if it needs to be oxygen, or if it can be air flowing through. Although most eye surgeries do not carry a combustion risk, as anesthesia providers we administer the oxygen and thus should always think about its need. Decreasing the $FiO_2$ as low as possible as a routine helps prevent the fire risk for those cases where combustion risk is present. In ophthalmic surgery, these are usually oculoplastic cases where the frequent use of cautery is utilized. Be ever mindful of fire risk!

## TAKE HOME POINTS

- Remember, the eye room is only a chip shot of a day if nothing goes wrong! You must always be mindful that the surgeons are operating on a direct extension of the CNS. Do not post your least-experienced person in there and assume that you can put the bulk of your attention in your other room.
- Communicate carefully with your patient to address and meet his or her expectations. Ask if the patient has a history of eye trauma or any other eye “phobia.”

- Remind your patient to minimize talking during the procedure, except as necessary to communicate about pain in the eye, the urge to cough, etc. Remind the staff to minimize chit-chat talking, as well. Also, we have found that sometimes patients tolerate the "eye" part of the procedure well, but have restless hands, since they are so often quite awake and alert. This can be quite distressing. We will sometimes roll up an OR towel for them to grasp lightly and give their hands something to do.
- Retrobulbar blocks have risks and some of them can be quite serious. You need to be vigilant and ready to treat seizures and cardiovascular complications from a misplaced block.
- Also, have the drugs ready to treat bradycardia and be vigilant for retraction and manipulation of the globe. Do not read in the eye rooms!
- Most, if not all, cataract and other patients who are having eye surgery awake will need some ventilation under the drapes. Use air if you can or otherwise minimize $O_2$ concentration. Never forget or discount the potential for fire. And remember, if you do have a fire complication, it is going to be right at the level of the patient's face.

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# My Eye Hurts! Prevention, Diagnosis, and Treatment of Corneal Injuries After Anesthesia

Raymond G. Graber, MD and David P. Martin, MD PhD

A 60-year-old male with past medical history of hyperthyroidism has just undergone a 4-hour robot-assisted radical prostatectomy, and is now waking up in the PACU. Now that the patient is more lucid, he is complaining of left eye irritation and pain. A colleague evaluates the patient, and states the following: "Patient complaint of eye irritation in PACU. No operative events noted that would result in corneal abrasion. Most likely the event occurred in PACU. Please consult Ophthalmology." Do you agree with this statement? How would **you** evaluate this patient?

## Introduction

The cornea is the transparent cover over the anterior part of the eye. The outermost layer of the cornea is the epithelium. This epithelium can be injured via a variety of methods, including trauma, exposure, and chemical irritation. The result is a defect in the corneal epithelium. There is a tendency to group all these mechanisms together and use the generic term "corneal abrasion" for any of these causes of epithelial defect. However, this is misleading, because the most common cause of perioperative corneal epithelial defects is probably not trauma, but exposure and drying. An irritation or injury can also involve the bulbar conjunctiva (the conjunctiva over the "white part" of the eye).

## Mechanisms of Injury

**Corneal Abrasions:** The epithelium can be damaged by direct trauma or rubbing. The classic scenario people worry about is the patient waking up from anesthesia and rubbing his or her eyes. A pulse oximeter on a finger can be poked in an eye. Airway management can be a time of trauma—from masks and fingers to dangling stethoscopes and IDs.

**Exposure Keratopathy:** Under normal circumstances, the tear film nourishes and

lubricates the cornea, aids in crisp visual acuity, and protects the cornea from bacterial invasion. Disruption of the tear film due to exposure and drying may lead to an epithelial defect. There are several factors that normally help maintain an adequate distribution of tears, including normal production of tears, an intact blink reflex, and complete eyelid closure during sleep and blinking. When a patient is under general anesthesia, these protective mechanisms are compromised. For example, basal tear production is about 25% of normal. Lack of complete eye closure (lagophthalmos) occurs in 59% of patients under general anesthesia (versus 4.6% of awake patients). Blinking does not occur, and corneal reflexes are abolished. Another factor is that patients are frequently exposed to high flows of oxygen by face mask in the recovery period or while under sedation in the operating room. Exposure keratopathy is also an issue in the patient who is intubated and sedated in the ICU setting.

**Chemical Keratopathy:** Various chemicals are toxic to the endothelium. In the operating room, the most common chemicals to worry about are the antiseptics. Of the antiseptics in use, products with 4% chlorhexidine appear to be toxic and should be avoided around the eyes.

## Incidence

The incidence of corneal injury depends on patient and procedure risk factors, and the type of preventive care used. Overall, if no preventive care is used (such as lubrication and taping), the incidence is 10% to 30%. With lubrication and eye taping, the incidence drops to 0.05% to 0.15%. So at a large center that does 25,000 surgeries per year, you would expect to see 10 to 30 corneal injuries per year.

## Risk Factors

**Patient Risk Factors:** In general, patients are at higher risk for corneal injury if there is a condition that predisposes to dry eyes or they have a preexisting injury. For example, patients greater than 50 years old and those with Sjogren syndrome tend to have less tear production. Patients who have protrusion of the eyeball (proptosis or exophthalmos secondary to hyperthyroid disease) or have facial palsies may have incomplete eye closure. There are also patients with recurrent erosions from contact lens use.

**Surgical Procedure Risk Factors:** Procedures involving the head and neck seem to have increased risk of corneal injury, either due to antiseptic chemical irritation or direct trauma. Another risk factor appears to be the development of conjunctival edema (chemosis). This bulging of the conjunctiva may cause loosening of eye tape and lead to conjunctival exposure. Significant conjunctival edema can be seen in multiple scenarios, such as when: (1) patients have received a lot of IV fluid, (2) in prone cases,

(3) in the dependent eye in lateral position cases, and (4) in the Trendelenburg position. The longer the time spent in these positions, the more likely there is to be an issue. There appears to be a higher risk of corneal injury in general when cases exceed 90 minutes. For example, it has been reported that long laparoscopic or robotic prostatectomies (which are typically performed in Trendelenburg position) have a higher incidence of associated corneal injury.

## Prevention of Corneal Injury

The key to prevention of corneal injury is maintenance of complete lid closure. Tape is usually used to seal the eyes shut, but sterile transparent IV dressings can also be used. If 4% chlorhexidine prep solution is being used anywhere near the eyes, then definitely seal the eyes with a transparent IV dressing. Ophthalmic ointments or gels have also been commonly used for corneal lubrication, and appear to have some additional protective benefit. Eye taping (alone) is probably adequate for cases without patient or procedural risk factors. However, if there are any risk factors, then the use of a lubricant is recommended.

## Corneal Lubrication Options

Ophthalmic ointments (containing petrolatum and mineral oil) have been commonly used for corneal lubrication. However, there is some controversy regarding their use because in some studies >50% of patients complained of blurred vision and eye irritation. On the other hand, studies do validate that the use of ointment reduces the incidence of corneal abrasion. To reduce the risk of eye irritation, preservative-free ointments should be used, and only in limited amounts. The proper dose is about a 1 cm ribbon (basically, as small of a dose as you can administer). **Patients do not want to cover the entire eyeball with lubricant.**

An alternative to ointments are methylcellulose gels. These do not appear to have the eye irritant potential that the ointments have, but they have a much shorter half-life in the eye. These are best used in patients with dry eye risk factors and shorter procedures (<90 minutes).

## Do You Really Need an Ophthalmology Consult?

If you were to get an ophthalmology consult for every case of eye irritation in the PACU, you would wind up with frustrated patients and delays in care. After all, how many PACUs have an ophthalmologist readily available to see a patient on a moment's notice? Instead, you can work with your local ophthalmologists to develop protocols for evaluation, treatment, follow-up, and documentation. A corneal abrasion diagnosis is

actually relatively simple to make. You can do it! And you can always consult a colleague if you are not sure. The exception would be if there is any indication of loss of vision. This complication, known as postoperative visual loss, may be secondary to ischemic optic neuropathy or central retinal artery occlusion. This mandates an immediate consult.

## Diagnosis

A corneal injury typically gets diagnosed in the PACU. Once the patient is adequately awake from their anesthetic, he/she will experience symptoms such as:

- Eye irritation, itching, or pain
- Eye redness
- Blurry vision
- Foreign body sensation
- Light sensitivity
- Tearing

To evaluate the patient, first examine the eye to rule out a foreign body, eye lash, and so forth. It is also a good practice to check that pupil reactivity to direct light is normal, to help rule out a more serious condition. If pupil reflex is abnormal, consult Ophthalmology.

To make a diagnosis of corneal injury, a fluorescein dye strip is wetted with sterile saline, the lower lid is pulled down, and the strip is touched to the inferior cul-de-sac. After the patient blinks to spread the dye, a cobalt blue light will show a corneal injury as a green line, spot, or patch if present. When the issue is a drying injury, the dye will frequently be seen in a line over the cornea where the lid was not completely closed. To facilitate this process, a corneal abrasion kit can be prepared and stored in a convenient location in the PACU (Fig. 146.1).

An alternative technique is to place one drop of proparacaine ophthalmic local anesthetic in the eye, and if the pain is completely relieved promptly, you can diagnose corneal injury. Proparacaine hydrochloride solution is a rapidly acting ester local anesthetic with induced anesthesia lasting approximately 10 to 20 minutes.

When in doubt, or if symptoms do not improve promptly as expected, it is always best to refer to ophthalmology. Injuries that are due to a chemical cause have the potential to be more severe, and should also be referred to ophthalmology.

## Prognosis and Treatment

Corneal abrasions usually heal rapidly and without further troubles, most often in the

first 24 to 48 hours after injury. Antibiotic prophylaxis is used to prevent infection while healing. Either drops or ointments can be used, but drops may be better tolerated by patients. Some example treatment options include: ciprofloxacin 1 drop QID for 2 days, erythromycin ointment TID for 2 days, or bacitracin ointment QID for 2 days.

Topical NSAIDs can be used for pain control. For example, diclofenac 1 drop QID for 2 days.

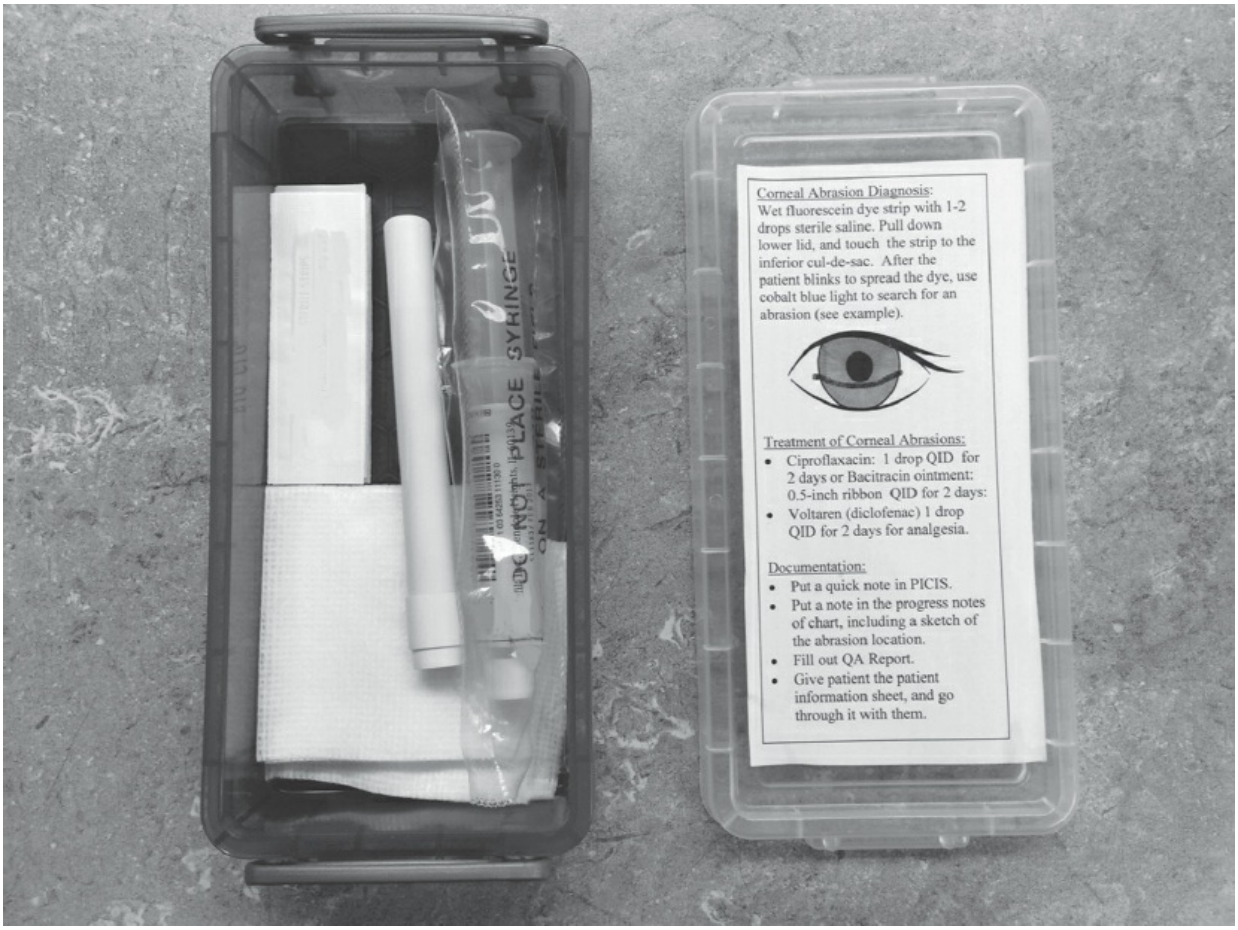


**Figure 146.1.** Corneal abrasion kit, with fluorescein dye strips, cobalt blue light, sterile saline, and instruction sheet. Available at www.hubrx.com.

## Supportive Care

Eye patching once was commonly used, but is now no longer recommended. Cold compresses can be used for 24 to 48 hours to reduce postoperative edema. Advise eye rest (i.e., no reading or work that requires substantial eye movement that might interfere with reepithelialization). Advise patients to avoid light or to wear sunglasses for comfort if they have notable photophobia. Contact lenses should be avoided for 7 days after surgery.

## Follow-up

Since most perioperative corneal injuries are secondary to drying, they should heal uneventfully, and ophthalmology follow-up may not be necessary. However, some patients are at higher risk for complications and should be seen in follow-up:

- If no improvement in 24 hours or complete relief in 48 hours
- If corneal abrasion due to known trauma to eye
- If vision deteriorates

## Documentation

After you examine a patient in PACU for possible corneal injury, the results of the fluorescein examination (including diagram of injury) and treatment provided should be documented in the progress notes of the chart. Many departments also track these incidents as part of their quality improvement activities. Patients should be given a "Corneal Abrasion Information Sheet" that summarizes the above information: (1) details what the diagnosis is, (2) what the treatment is, (3) supportive care, and (4) when they should seek ophthalmology follow-up).

## What Can My Center Do to Decrease the Incidence of Corneal Injuries?

Researchers at the Department of Anesthesiology at the Mayo Clinic performed a performance improvement study to see how they could impact their rate of perioperative corneal injury. The majority of corneal injuries experienced were due to corneal exposure (that is the eyelids were incompletely taped shut). Therefore, they instituted an educational program to recommend the use of protective eye ointment and proper eye taping technique (early application of eye tapes during induction process and ensuring that the eyelids are completely shut). Simple education did not result in a significant decrease in the rate of corneal injury. However, what did work was the combination of notification of the team members when an injury occurred, in combination with a link to education about corneal injury prevention measures. In other words, the injury triggered ongoing education, which is particularly relevant in academic practices where there is a large turnover of personnel in training. By coupling outcomes to relevant education in real time, they demonstrated that significant and sustained clinical improvements could be achieved. The incidence of corneal injury dropped from 1.51 per 1,000 surgeries as baseline, to 0.47 per 1,000 surgeries at the end of the study period.

### TAKE HOME POINTS

- When you are called about a patient with eye discomfort, take ownership of the

problem and see the patient expeditiously. It may turn out to be something minor, but it could be something major, too.

- Patients who have general anesthesia have a risk of corneal injury.
- The most common cause of corneal injury during anesthesia is exposure and drying. Trauma and chemical injuries are less common causes.
- There are both patient risk factors and procedure risk factors that increase the chance of getting a corneal injury.
- The incidence of corneal abrasion is reduced when proper lubrication and eye taping is performed.
- Work with your local ophthalmologists to develop treatment protocols.

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# Never Forget That Patient Transport Within the Hospital Is One of the Most Dangerous Intervals in the Perioperative Period

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A 45-year-old woman with history of anxiety and IV drug abuse is hospitalized for endocarditis, sepsis, and resultant heart failure. She has developed ARDS requiring high PEEP and prolonged intubation, and is also dependent on a stable low-dose norepinephrine infusion. Anesthesiology has been consulted to accompany the patient from ICU to OR for tracheostomy placement. What considerations for sedation, ventilation/oxygenation, and hemodynamic management must be taken prior to transporting this patient?

## Introduction to Intrahospital Transport (IHT)

Transport of a critically ill patient from one location in the hospital to another is associated with increased risk of adverse events and causes significant patient morbidity. Anesthesiologists often participate in the transport of critically ill patients to and from the operating room as well as other locations (such as diagnostic and interventional suites) where anesthesia services are provided. It is important for the anesthesiologist to anticipate potential problems that may be encountered during transport and be prepared with necessary medicines and equipment that may be required en route. While this chapter focuses on transporting the critically ill, escort from the operating room to PACU after a routine anesthetic is, by definition, a transport to a critical care unit and many of the same principles discussed will still apply.

## Risks Associated With Intrahospital Transport

Critically ill patients require frequent, minute-to-minute assessment and intervention to maintain a stable physiologic homeostasis. The first decision that must be made before moving an ICU patient is whether the transport is an immediate necessity or whether the

patient should or could be further optimized prior to transport. Some healthcare delivery systems have established recommendations for suitability for IHT based on duration of hemodynamic stability and necessity of transport. Leaving the ICU setting not only puts the patient at risk for omission of planned interventions (such as missing scheduled medication administrations or pulmonary hygiene), but can also create or exacerbate a medical condition in a new location in the hospital where rapid, life-saving diagnoses and interventions are not readily available. Transport itself can cause physiologic derangement due to changes in ventilation, disruption of airway or infusion equipment, and even simply turning or moving the patient.

Compared to ICU patients who are never exposed to IHT, patients who require transport out of the ICU are typically "sicker" based on well-recognized illness severity scores. While there is no conclusive evidence that IHT is associated with increased mortality**, transported patients are documented to have higher frequency of adverse events during and after transport**, which often results in need for additional interventions and significantly increases the length of ICU stay. It is uncertain, however, whether these findings reflect the fact that those patients who required IHT had higher overall illness severity scores prior to transport, which could independently account for their higher rates of complication and longer stays. Specific reported complications that appear to be related to intrahospital transfer include the following.

## Neurologic Complications

- **Undersedation**—Inadequate sedation puts patients at risk for self-injury, self-extubation, difficulty ventilating or oxygenating, and undesired elevations in blood and intracranial pressure. Use of paralytics may confound a patient's neurologic examination for many hours.
- **Oversedation**—Excessive sedation in patients without an advanced airway (such as a nonintubated patient getting an MRI) creates a situation where emergent airway management must be undertaken in a suboptimal location.
- **ICP derangement**—Changes in ICP may occur due to repositioning of head of bed or externalized CSF drains, or hypo/hyperventilation.

## Pulmonary Complications

- **Ventilator-associated pneumonia (VAP)**— In some studies, patients who were exposed to IHT were reported to have higher incidence of VAP, perhaps due to leakage of supraglottic secretions around a manipulated endotracheal tube or development of atelectasis.
- **Pneumothorax**—Barotrauma may occur during bag ventilation, especially with suboptimal technique.

- **Hyper/hypoventilation and/or oxygenation**—Some studies have observed changes in $PaCO_2$ or $PaO_2$ that persisted at least 24 hours after IHT.

## Cardiovascular Complications

- **Hemodynamic instability**—Transport can be a source of stimulation, and changes in positioning often causes hemodynamic change. Fluids or pressors necessary to treat the hypotensive patient may not be immediately available.
- **Bleeding or thrombosis**—Due to interruptions in monitoring or titration of anticoagulants.
- **Pulmonary embolism**—Changes of patient position could possibly cause mobilization of unstable clot.
- **Inadvertent loss of vascular access.**

## Other Complications

- **Hypernatremia**—Due to loss of frequent electrolyte and fluid monitoring and/or correction in at-risk patients
- **Hyper/hypoglycemia**—Resulting from interruption of feeding or insulin schedules
- **Missed medication administration and therapies available in the ICU (respiratory and/or physical therapy)**
- **Missed or delayed diagnosis**

## Avoiding Common Errors: Considerations for Transporting Patients

) Determine whether the patient should be transported at all (i.e., will the trip change the patient's management or outcome?). Could the patient be optimized prior to transport? Could a procedure be performed bedside?

) Be prepared to provide additional sedation in the event the patient "wakes up," becomes combative, or bites down on the endotracheal tube.

) Maintain a patent airway during transport. What are the consequences of inadvertent extubation (by the patient or providers)? Consider taking rescue airway equipment such as a bite block, positive pressure mask, LMA, or laryngoscope before transporting an intubated patient.

) Take enough oxygen for the trip. Some ventilation systems (such as Jackson-Rees bag ventilators) are dependent on fresh oxygen flow. As a rule of thumb, a full E-cylinder at 10 L/min will provide approximately 1 hour of oxygen delivery.

) Plan a ventilation strategy. Ambu-type bags, Mapleson circuits (such as Jackson-Rees), and mobile ventilators are all options. Note ventilator settings, especially in patients with ARDS or requiring high PEEP, and utilize a ventilation strategy during the transport that can approximate prior settings. Note that Ambu-bags do not deliver PEEP unless fitted with a PEEP valve, and while Jackson-Rees can provide PEEP, it also requires continuous flow of oxygen and runs a higher risk of barotrauma.

) Continue necessary infusions, and have the ability to bolus pressors and sedating medicines.

') Be prepared to administer ACLS.

) Select appropriate monitors for transport. Ensure that batteries for infusion pumps, monitors, ventilators, and pacemakers are adequately charged.

) Plan a route and take appropriate personnel. Transport should always involve another individual who is capable of rendering whatever level of care is necessary. A medical student is nice to have along for the trip, but should not substitute for a trained anesthesia provider.

0) Get and give a handoff report with all appropriate team members present.

For the critically ill patient, physical movement from one location in the hospital to another represents a period of increased risk of morbidity. Anesthesiologists have an opportunity to reduce that risk as they are often the responsible providers during the time of transport, and are well equipped to manage most immediate life-threatening emergencies that may develop as a result, provided they anticipate problems and prepare accordingly.

## TAKE HOME POINTS

- Keep your patient safe during transport by first recognizing the need to do so.
- The editors have seen just about every complication during transport that you can think of. This includes extubated patients, inadvertent boluses of pressors and nitroprusside, disconnected arterial lines, disconnected large-bore central venous access, dislodged pulmonary artery catheters, and cardiac arrest.
- If manpower allows, we recommend that specific duties be assigned to the individual transport team members. One person bags the patient and makes sure he or she does not become extubated. Another person keeps an eye on the drips, poles, and pumps and has the necessary emergency drugs and so forth.
- Make sure you can always get to a stopcock that has a free-flowing bag of IV solution hooked up to it. We will often establish such access by taping the stopcock

to the patient's pillow so that it is available to both people walking at the top of the bed.

- Predraw **and label** any drugs you think you might need for the trip. You never want to be in the position of having to stop in the hallway to draw up drugs.
- Consider putting a piece of red tape over the stopcocks in the arterial line setups for the hallway transport and while you are positioning the patient on the OR table. You want to be able to identify in a second which are the venous access lines and which are arterial lines.
- Go carefully and as slowly as you need to safely get the job done while taking into account the surgical acuity. Stay calm and communicate!

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# Seek Out Hypercapnia in the PACU and Remember That an Acceptable Pulse Oximeter Reading Is Not Assurance of Adequate Ventilation

Michael P. Hutchens, MD MA

"Global warming is not the only downside of elevated $CO_2$ concentration"

Respiratory complications are common events in the postanesthesia care unit (PACU)—as many as 7% of patients require upper-airway support of some kind during their PACU course. Although pulse oximetry provides excellent monitoring of arterial oxygen saturation, it is an anesthesia truism that reduced arterial oxygen saturation due to hypoventilation in patients receiving supplemental oxygen is a late finding. The physiologic manifestations of hypercapnia are truly protean, and although central nervous system effects are noticeable in patients who are awake, these findings, and others, may be masked by the shifting perioperative milieu. Hypercapnia both results from and causes respiratory arrest and is usually easily reversible in the PACU patient if caught in time.

Carbon dioxide ($CO_2$) is an odorless, colorless, heavier-than-air gas, which, apart from oxygen and water, may be the most ubiquitous drug in medicine. Anesthesiologists routinely manipulate the $CO_2$ content of blood to achieve physiologic goals. It is endogenously produced as a byproduct of energy production by degradation of carbohydrates in the Krebs cycle. Although physiologic investigation of the effects of $CO_2$ began during the Enlightenment, its toxic effects were known in antiquity from the occasional (sometimes intentional) lethal encounter between living beings and caves with elevated $CO_2$ concentration. Indeed, $CO_2$ is itself a general anesthetic; it is currently used for laboratory animal euthanasia and sedation of livestock before slaughter. Experimentation in the 1960s using monkeys and cats breathing a 50:50 mix of $CO_2$ and oxygen demonstrated electroencephalogram (EEG) slowing to isoelectricity

after initial activation. Unlike the mechanism of conventional inhalational anesthetics, the mechanism of $CO_2$ anesthesia is thought to be an effect of locally induced brain acidosis. In an elegant paper published in 1967, Eisele et al. measured the $PaCO_2$ at which response to surgical stimulus was abolished in 50% of experimental dogs as 222 mm Hg; this is, in essence, the MAC in dogs of $CO_2$. Thirty-percent $CO_2$, in oxygen administered by mask to human beings, produces anesthesia, but produces a foul acidic taste in the mouth and feelings of anxiety and dyspnea. As $PaCO_2$ rises above 90 mm Hg, human beings exhibit stupor and, ultimately, loss of consciousness.

$CO_2$, whether exogenously or endogenously sourced, has significant physiologic effects apart from those on consciousness. Hypercapnia increases cerebral blood flow and, thus, intracranial pressure. $CO_2$ is a pulmonary vasoconstrictor, however, and causes a predictable increase in pulmonary artery pressures at elevated levels. Because of the Bohr effect, hypercapnia decreases hemoglobin affinity for oxygen. An increased $CO_2$ level also causes systemic hypertension, both from increased cardiac output and arteriolar vasoconstriction. An elevated $PaCO_2$ is proarrhythmic, particularly in the presence of halothane. Hyperkalemia can result from release of cellular potassium stores, and at a very high $PaCO_2$, glomerular filtration rate is reduced by afferent arteriolar vasoconstriction. Interestingly, a brief review of the literature reveals multiple cases of $PaCO_2$ levels of more than 200; these patients (mostly children) were stuporous or comatose but, in the absence of hypoxemia, recovered without permanent deficit.

In the immediate perioperative period, it is not unusual to encounter a stuporous (or anxious) patient with abnormal vital signs. While these aberrations are most commonly caused by residual anesthetic, pain, or medication, they can all be caused by hypercapnia as well. Since extubated patients in the PACU do not usually have their end-tidal $CO_2$ displayed on the monitor, it is up to the clinician to suspect and diagnose hypercapnia from clinical data. Patients in the PACU have two excellent reasons to become hypercapnic. They almost universally receive medications that depress their respiratory drive, and they therefore frequently hypoventilate. Secondly, as patients emerge from anesthesia, their basal metabolic rate increases, and, as a result, they may have increased production of $CO_2$, thus increasing the relative impact of hypoventilation. Shivering increases this effect, as do agitation and fever. Malignant hyperthermia causes a sustained increase in $CO_2$ production, but other systemic signs are usually present.

While reduced respiratory rate is one mechanism for hypoventilation, patients who are splinting may hypoventilate while breathing rapidly and taking small breaths. Patients with obstructive sleep apnea or postanesthetic airway obstruction may have a

normal respiratory rate but only transport gas during a short part of the respiratory cycle, thus reducing their alveolar ventilation. **Regardless of the etiology, the clinician must have a high index of suspicion for hypercapnia in the postoperative patient. Since it often results in end-organ dysfunction, it must be treated quickly.** Patients who have decreased respiratory drive from opioid administration should receive naloxone, 40 µg every 1 to 2 minutes, intravenously, until their respiratory rate and level of consciousness increase. Patients who are apneic from opioids, or imminently apneic, should of course receive bag-mask ventilation, and the clinician should consider administering a larger dose of naloxone intravenously (the maximum single dose is 400 µg). Patients with obstructive sleep apnea may benefit from the application of noninvasive ventilation. Patients with splinting can be the most challenging; their hypercapnia paradoxically improves with opioid administration. The clinician must be confident of this etiology before treating it, and, ultimately, these patients may benefit most from regional analgesia. As always, endotracheal intubation and mechanical ventilation are the definitive treatments and should be considered early, while they are still optional, rather than late, when control of the airway becomes emergent.

$CO_2$ is a powerful drug that affects the physiology and care of the postoperative patient. Regardless of the etiology, the clinician must have a high index of suspicion for hypercapnia. Since it often results in end-organ dysfunction, it must be diagnosed and treated quickly to prevent such dramatic physiologic consequences as intracranial hypertension, confusion, stupor, coma, respiratory arrest, and death.

## TAKE HOME POINTS

- Respiratory events in the PACU are common.
- Patients in the PACU are at high risk of hypercapnia.
- The onset of hypercapnia may be masked by other perioperative conditions.
- $CO_2$ is a general anesthetic and loss of consciousness occurs above a $PaCO_2$ level of about 90.
- $CO_2$ is a powerful drug that affects intracranial pressure, hemodynamics, oxygen transport, renal function, and other physiologic parameters.

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# Let's Go Over It Again: Avoid Residual Neuromuscular Blockade in the PACU!

Eleanor Anne Vega, MD and Ryan J. Fink, MD

Nondepolarizing neuromuscular blocking drugs (NMBDs) are a staple in the anesthesiologist's toolbox. These agents have numerous benefits, including facilitating endotracheal intubation, optimizing operating conditions, and protecting the patient from harm due to movement during critical portions of an operation. While muscle relaxation may be desired in the operating room, residual paralysis can cause serious complications in the postoperative period. Patients who receive a nondepolarizing NMBD must be managed carefully to ensure that full recovery of neuromuscular function occurs prior to extubation.

## How Does Residual Neuromuscular Blockade Manifest and Why Does It Matter?

Patients who have complete recovery of neuromuscular function will be able to breathe normally, cough, protect their airway with intact airway reflexes, maintain a patent upper airway, and swallow. Residual paralysis manifests in a myriad of clinical signs and symptoms, which can result in various complications. Signs of neuromuscular blockade in the postanesthesia care unit (PACU) include weakness of pharyngeal muscles, swallowing dysfunction, decreased inspiratory airflow, reduction in upper airway volumes, and impaired hypoxic ventilatory drive. A variety of associated adverse events have been reported, including hypoxemia, hypercarbia, airway obstruction, aspiration, pulmonary complications such as atelectasis or pneumonia, and need for emergent reintubation that may result in prolonged PACU stays and/or unexpected ICU admissions. The most common complaints by patients with incomplete neuromuscular recovery are generalized weakness, visual disturbances such as diplopia or blurry vision, and difficulty speaking. Even the in absence of objective clinical signs, these subjective symptoms can be very distressing to patients.

Most anesthesiologists report that they have never seen a case of postoperative residual neuromuscular blockade, but studies demonstrate that up to 64% of patients

arrive at the PACU with some level of residual paralysis. Such poor recognition is due to a lack of appropriate monitoring and confounding variables that may mask the diagnosis, such as opioid use, residual inhaled or intravenous anesthetics, hypothermia, and electrolyte imbalances.

## How Can the Incidence of Residual Paralysis in the PACU Be Reduced?

A simple, reliable, readily available test, with both high sensitivity and high specificity, does not exist to evaluate neuromuscular function. In addition, the utility of reversal drugs currently available in the United States is limited by a ceiling effect. The maximal effectiveness of these medications also depends on appropriate dose and timing of administration. Until better monitors and reversal agents are available, a variety of strategies must be employed to reduce the risk of residual paralysis after nondepolarizing NMBD administration. Currently, no guidelines exist from the American Society of Anesthesiologists (ASA) on recommended use and reversal of these drugs.

## Judicious Use of Neuromuscular Blocking Drugs

Careful consideration of how nondepolarizing NMBDs are administered will minimize untoward side effects such as residual paralysis. First, determine whether nondepolarizing NMBDs are necessary at all. Can the patient be safely managed through the operation without a nondepolarizing NMBD? Consider using a laryngeal mask airway without muscle relaxation if appropriate for the patient and operation. Succinylcholine may be a viable option to facilitate endotracheal intubation for short surgeries, if not contraindicated. Avoiding nondepolarizing NMBDs altogether drastically decreases the risk of weakness in the PACU.

If a nondepolarizing NMBD is needed for endotracheal intubation, choose an intermediate-acting drug, such as rocuronium or vecuronium, over long-acting pancuronium, as the former are associated with fewer signs of residual paralysis and resulting complications. Next, determine whether repeat doses of the NBMD are needed to maintain muscle relaxation. Does the surgeon require full paralysis to safely and efficiently perform the operation? It may be possible to optimize operating conditions simply by maintaining a deep anesthetic, administering adequate opioids, and using appropriate ventilator settings.

When muscle relaxation is required throughout the procedure, use a peripheral nerve stimulator to determine redosing interval of the nondepolarizing NMBD. There is rarely a need to maintain zero twitches; waiting until 2 or 3 twitches are present (out of 4) to redose will reduce the total amount of drug administered, allow for earlier reversal, and

may reduce the risk of postoperative residual paralysis. (Peripheral nerve stimulators and twitches are discussed in further detail below.)

The goal of nondepolarizing NMBD administration should be to use as much as, but no more than, is clinically indicated to maintain patient safety in the operating room.

## Evaluating for Neuromuscular Blockade

There are two common methods to evaluate a patient's neuromuscular function in the perioperative setting: clinical tests and neuromuscular monitors.

## Clinical Tests

To determine a patient's readiness for extubation, it is common to have the patient perform such tasks as a 5-second head lift or a hand squeeze to evaluate grip strength. If the patient is able to follow commands and "pass" these tests, the patient is deemed suitable for extubation. The majority of anesthesiologists in the United States believe that the head-lift test is an adequate predictor of recovery of neuromuscular function. Unfortunately, data show that these tests are extremely unreliable and not sensitive to detect residual neuromuscular blockade. Patients that easily "pass" these clinical tests in the OR prior to extubation can arrive in the PACU with significant residual paralysis. While these tests are not sensitive, they are relatively specific; if the patient "fails" the tests, they almost certainly have significant residual neuromuscular block. Therefore, these clinical tests can help rule in, but not rule out, residual neuromuscular weakness.

## Neuromuscular Monitors

Neuromuscular monitors are not considered standard required monitors by the ASA. Not surprisingly, the majority of anesthesia practitioners in the United States do not routinely use them. There are two categories of neuromuscular monitors: qualitative and quantitative.

### Qualitative Monitors

Peripheral nerve stimulators are used to obtain a qualitative, or subjective, measure of neuromuscular blockade. These devices electrically stimulate a peripheral nerve (often the ulnar nerve) while the clinician assesses the motor response (in the thumb) in either a visual or tactile manner. A popular mode on the nerve stimulator is called the "train-of-four" (TOF), where four stimuli are given in succession. The height or strength of the fourth motor response ("twitch") is divided by the height or strength of the first twitch to give us the train-of-four ratio (TOFR). Fade is present when the height of the fourth twitch is less than that of the first twitch. As the fade increases, the TOFR decreases; this corresponds to a greater intensity of the neuromuscular blockade. When the height

of the fourth twitch equals or closely equals that of the first twitch (TOFR ≥0.9, or no fade), neuromuscular function is assumed to have fully recovered. Patients should not be extubated until TOFR is ≥0.9, or they will be at risk of the signs and symptoms of residual paralysis discussed earlier. Unfortunately, even experienced clinicians are not able to detect fade when the TOFR is >0.4. If using these qualitative methods, the clinician may believe that the patient has made a full neuromuscular recovery (i.e., no fade is detected) and is safe for extubation, when in reality, they could have significant residual paralysis (TOFR between 0.4 and 0.8).

### Quantitative Monitors

With quantitative methods of determining the TOFR, the device itself measures the motor response to the peripheral nerve stimulation and provides a numerical value of TOFR. The two most common types of these devices are based on mechanomyography (MMG) and acceleromyography (AMG). MMG devices are mostly used in research settings, while AMG devices are available for clinical use. Studies show that using a quantitative method of monitoring neuromuscular function reduces the incidence of both signs and symptoms of residual neuromuscular blockade in the PACU when compared with qualitative methods. There are some limitations to the AMG monitors. Because they detect acceleration of a muscle or digit after stimulation, they may be inaccurate and unreliable in awake, spontaneously moving patients (i.e., patients in the PACU). In addition, the devices are fragile, can be easily broken, and require special training. Only 20% of anesthesiologists even have access to quantitative monitors at their hospitals. The authors encourage anesthesia providers to have these types of monitors available, as they have been shown to be superior to other forms of clinical assessment of neuromuscular blockade. Quantitative assessment of neuromuscular function prior to extubation is probably the most important in patients who are at high risk of complications from residual paralysis, such as those with preexisting neuromuscular disorders, bulbar dysfunction, difficult airways, or severe pulmonary disease.

## Reversal Agents

Great variability is seen in the duration of action of nondepolarizing NMBDs; an intubating dose of rocuronium or vecuronium may last anywhere from 1 to 4 hours. In the absence of quantitative monitoring demonstrating complete recovery of neuromuscular function (TOFR ≥0.9), an acetylcholinesterase inhibitor should be administered to reverse the effects of nondepolarizing NMBDs. Routine administration of reversal agents after nondepolarizing NMBDs has been shown to decrease the incidence of residual neuromuscular blockade. Appropriate timing of reversal is also crucial. These drugs can take 15 to 20 minutes to reach full effect, so they should be

given well before extubation. Reversal agents have a ceiling effect, so it is best to administer reversal when the twitch count on TOF stimulation is maximal (4/4).

## Conclusion

It may not be possible to completely eliminate residual neuromuscular blockade in the postoperative period until better neuromuscular monitoring devices and reversal agents are made available. For now, it is imperative to design an anesthetic plan aimed at mitigating the risk of residual paralysis. The incidence of this potentially serious complication can be greatly reduced by thoughtful administration of neuromuscular blocking agents and reversal drugs, and the use of appropriate quantitative neuromuscular monitoring devices to evaluate neuromuscular function.

### TAKE HOME POINTS

- Residual neuromuscular blockade is a common and serious patient safety issue that usually manifests with pharyngeal muscle, upper airway, and generalized weakness, and visual disturbances.
- Residual paralysis can lead to complications in the PACU such as hypoxemia, hypercarbia, aspiration, prolonged PACU stay, need for reintubation, and unexpected ICU admission.
- The perfect monitor of neuromuscular function does not exist, nor does the perfect reversal drug. Therefore, anesthesia providers must use all available tools to reduce the risk of residual neuromuscular blockade.
- Be judicious in the use of nondepolarizing neuromuscular blocking drugs. Avoid or minimize these drugs when appropriate. Choose intermediate-acting over long-acting NMBDs.
- Monitor neuromuscular function on every patient who receives a nondepolarizing NMBD. If possible, use a quantitative method (such as AMG), especially on patients at high risk for complications of residual neuromuscular blockade. If quantitative methods are not available, use qualitative methods (peripheral nerve stimulation) to assess neuromuscular recovery.
- Clinical tests, such as head lift and grip strength, cannot rule out residual neuromuscular blockade, but can be used along with neuromuscular monitoring to help diagnose residual weakness.
- Consider administering reversal agents (acetylcholinesterase inhibitors) to every patient who receives nondepolarizing NMBDs. Dose reversal agents at least 15 to 20 minutes prior to extubation and preferably when 4/4 twitches are present.

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# Give the Intensivist the Best Handover to Improve Patient Outcomes

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Approximately 40 million patients undergo surgery in the United States every year and patients are subsequently transferred to a postanesthesia care unit (PACU) or intensive care unit (ICU) for recovery. After a complex anesthetic for a sick patient, ICU transfer and care handover remains a final critical element prior to completion of the case. With substantial information to relay to the ICU team and potential cognitive fatigue, the ICU handover process is high risk for communication failures, including incomplete or inaccurate information relay. A recent study from 2008 used Six Sigma methodology and found three barriers to safe handovers: (1) inconsistent clinician participation; (2) inconsistent standardization of handover content and process; (3) the presence of interruptions and distractions. In this section, we propose several strategies to improve patient safety and outcomes during the ICU handover process.

## Use Standardized Handover Tools

Written checklists in any format are useful cognitive aids to ensure that comprehensive data transfer is efficient and effective. These handover tools are ideally reviewed and endorsed by providers on both ends of the handover team and continually assessed for quality. Handover aids are widely recommended in current literature. With a complete and organized approach, the receiving team will better understand and anticipate immediate patient care issues. Consider starting the form or checklist during a stable intraoperative period to ensure a smooth handover process with adequate preparation. Research has shown that using handoff tools consistently improves efficacy of data transfer, efficiency, and improve provider satisfaction.

## Prioritize the Handover Process

With the understanding that the ICU handover is a high-risk environment for communication failures, we recommend that the handoff process be prioritized as a critical step in patient care. Complete urgent orders, tasks, documentation, and drip

changes prior the handover to ensure sufficient focus. Anticipate issues that may arise immediately postoperatively and propose a plan. Minimize interruptions for noncritical issues or about other patients. **We suggest adopting the "sterile cockpit" approach where only patient-specific discussions occur during the handover process.** Make it your goal to assemble all relevant information prior to the handover to assure pertinent information is at your fingertips—this may include recent lab results, preoperative echocardiograms, intraoperative labs, totals for ins and outs and medications administered, and current drip settings. Only one provider should speak at a time. Research has shown that interruptions rapidly degrade the quality of handovers.

## Assemble the Entire Team

Before starting the handover ensure that all team members are present including ICU providers, RNs, and respiratory therapy staff (if applicable) to maximize direct information transfer from you. Engage all team members in discussion by introducing yourself and the patient with an appropriate patient identifier statement (name, age, sex, and procedure).

## Improve the Handover Process Continually

Ensure that handoffs are safe and effective by reviewing the process methodology and engage handover speakers and listeners. Handover standardization addresses a Joint Commission safety goal. Provide training for learners by teaching effective and clear communication skills.

## Pitfalls to Avoid

Common pitfalls that result in poor quality handovers include incompletely transferring information, lack of consistency, distractions, and inefficient execution of clinical tasks. Of these, poor communication has been shown to adversely affect patient outcomes in the PACU and ICU settings, and may be one of the easiest to avoid with communication standardization and handoff tools. By standardizing and streamlining information transfer, receiving teams have a deeper understanding of the patient and potential postoperative problems.

## Summary

There are many elements that contribute to a successful, safe, and efficient patient handover. We recommend using standardized handover tools, prioritizing the process, assembling the entire team, and continually improving the process. Remember that transfer of care is a critical element of patient care, and that the anesthesiologist plays a

crucial role in communicating important information from the preoperative and intraoperative setting that will impact subsequent care delivery.

## TAKE HOME POINTS

- The first step in completing a thorough and effective patient signout in the ICU is understanding the importance of doing so.
- ICU handovers can be analyzed using Six Sigma methodology. These studies have shown that the barriers to safe handovers involve inconsistent clinician participation, inconsistent standardization of handover content and process, and the occurrence of interruptions and distractions.
- The signout preliminaries can start when you are still in the OR. The senior anesthesiologists among us will occasionally call the ICU in the hour or so before the case of the case and before we start "packing up" the patient for transport, especially if the case has been a long and difficult one or if there is an unforeseen postoperative intubation planned. One of the editors will also sometimes put a quick call into the attending intensivist if it is in the evening and he or she is not in-house, just to hit the highlights of the case.
- Prioritize the handover once you get to the ICU. Concentrate only on the patient in front of you. Do not take or ask questions about your next case.
- Assemble all caregivers at the time of handover. Don't play the "telephone game" and don't let the information get distorted as it is repeated from provider to provider.

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# Don’t Miss Out on Ultrasound—Which ICU Techniques Are Helpful for the Anesthesiologist?

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## Introduction

Ultrasound is a fundamental tool for aiding diagnosis and guiding therapeutic interventions, and its use dramatically improves the safety and efficacy of many commonly performed invasive procedures. This chapter discusses three ultrasound techniques commonly performed in the intensive care unit (ICU) that are also of particular interest to the anesthesiologist: (1) focused lung ultrasound, (2) focused cardiac ultrasound, and (3) ultrasound for difficult vascular access.

## Focused Lung Ultrasound

Ultrasound waves are scattered and attenuated by air. Thus normal lung can be difficult to visualize with ultrasound, but lung that is filled with or surrounded by fluid is relatively easy to image.

Using ultrasound, the pleural space may be readily assessed for pneumothorax. To evaluate the pleura, place the ultrasound probe anteriorly on the patient’s chest between two ribs (on the screen the ribs appear as two dark shadows on either side of the probe). In the absence of pathology, the pleura is seen as a shimmering, echolucent line deep to the ribs that slides back and forth during inspiration and expiration. This “lung sliding” may be evaluated with 2-dimensional (2D) ultrasound or M-mode. M-mode shows the movement of structures intersecting a single line over time. An area of lung sliding that appears and disappears during respiration is called the “lung point” and signifies that the edge of a pneumothorax is coming in and out of view. The presence of lung sliding has a negative predictive value of 100% for anterior pneumothorax in the supine patient. However, the absence of lung sliding is not specific for pneumothorax, as any condition that decreases air movement may cause this phenomenon.

A pleural effusion may also be detected with ultrasound. Position the probe between two ribs, this time in the posterior axillary line with the patient in the supine or lateral decubitus position, since a free-flowing effusion tends to layer in a dependent fashion. When present, an effusion appears dark on ultrasound due to its low echogenicity. Adjacent structures, including lung parenchyma, are often seen deep to the effusion. Gleaning additional information about the nature of the effusion based on its echogenicity, the presence or absence of septae, and its qualitative volume is also possible.

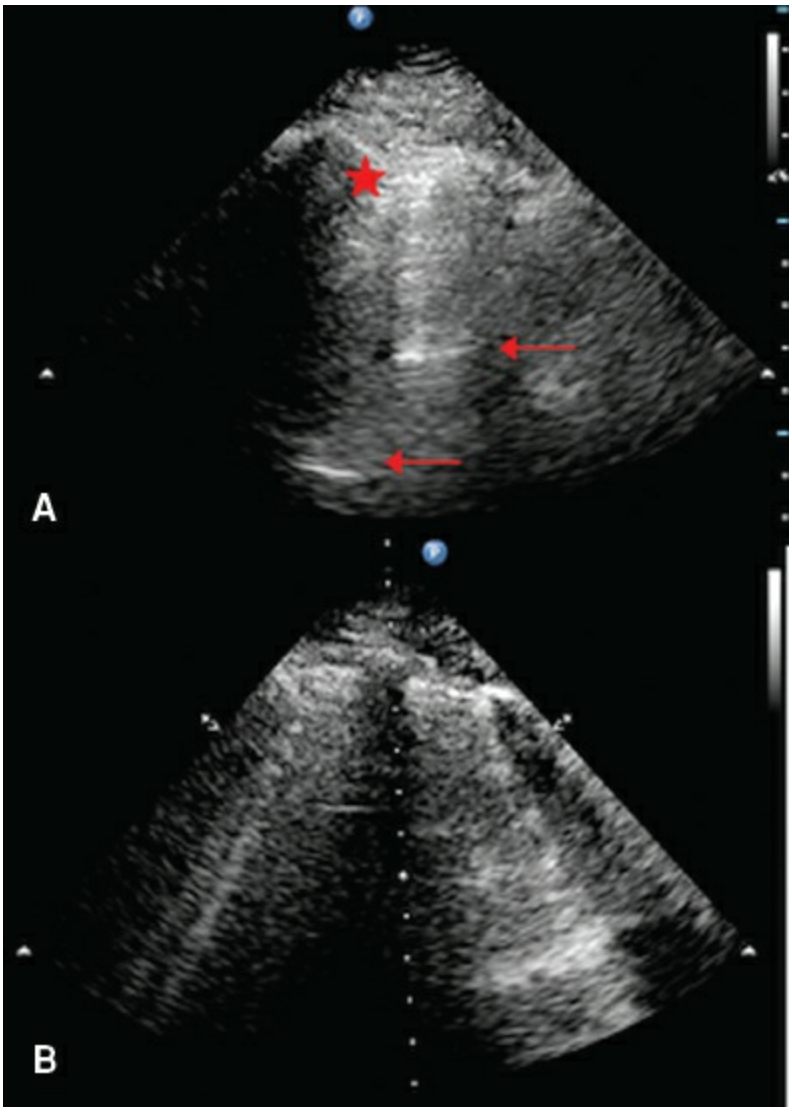


**Figure 151.1.** **A:** A-lines on lung ultrasound are indicated by arrows. Note the parallel curvature to the pleura, indicated by the star. **B:** B-lines on lung ultrasound are indicated by the arrows. Note the perpendicular orientation with regard to the pleura and the absence of A-lines in the region of the B-lines.

Finally, the lung parenchyma itself may be evaluated. Look for equally spaced horizontal lines deep and parallel to the pleural line. These "A-lines" are an artifact that occurs when the pleural signal is reverberated and reflected back toward the ultrasound

transducer (Fig. 151.1). When observed in the presence of lung sliding A-lines highly suggest normally aerated lung. When A-lines are present in the absence of lung sliding this finding is 95% sensitive and 94% specific for occult pneumothorax. Thus, A-lines can be used to evaluate the lung parenchyma as well as to help rule out pneumothorax.

When the air-filled spaces in the lung become fluid-filled due to pulmonary edema or consolidation, A-lines are replaced by "B-lines" (Fig. 151.1). B-lines radiate from the pleural line to the edges of the ultrasound screen, in a plane perpendicular to the pleural line. B-lines are also known as "comet tail artifacts" (when few are present) or "lung rockets" (when many are present). Although B-lines indicate a predominance of fluid-filled airspaces, no clear correlation exists between the appearance or type of B-lines and the patient's overall volume status.

## Focused Cardiac Ultrasound

The focused (transthoracic) cardiac ultrasound examination (CUE) is useful for assessing hemodynamically unstable patients. Although transesophageal echocardiography has many clear advantages in the intraoperative setting, benefits of the CUE include that it is noninvasive, quick, safe, and easily performed in either the patient who is awake or under general anesthesia. The CUE tends to be of limited value when air is in the chest (i.e., postcardiac or thoracic surgery), or when the surgical site, drains, or bandages obscure access to the thorax.

The CUE consists of four main echocardiographic windows: (1) parasternal short axis, (2) parasternal longitudinal axis, (3) apical four chamber, and (4) subxiphoid. Each view is complementary and provides valuable information about cardiac function (Fig. 151.2).

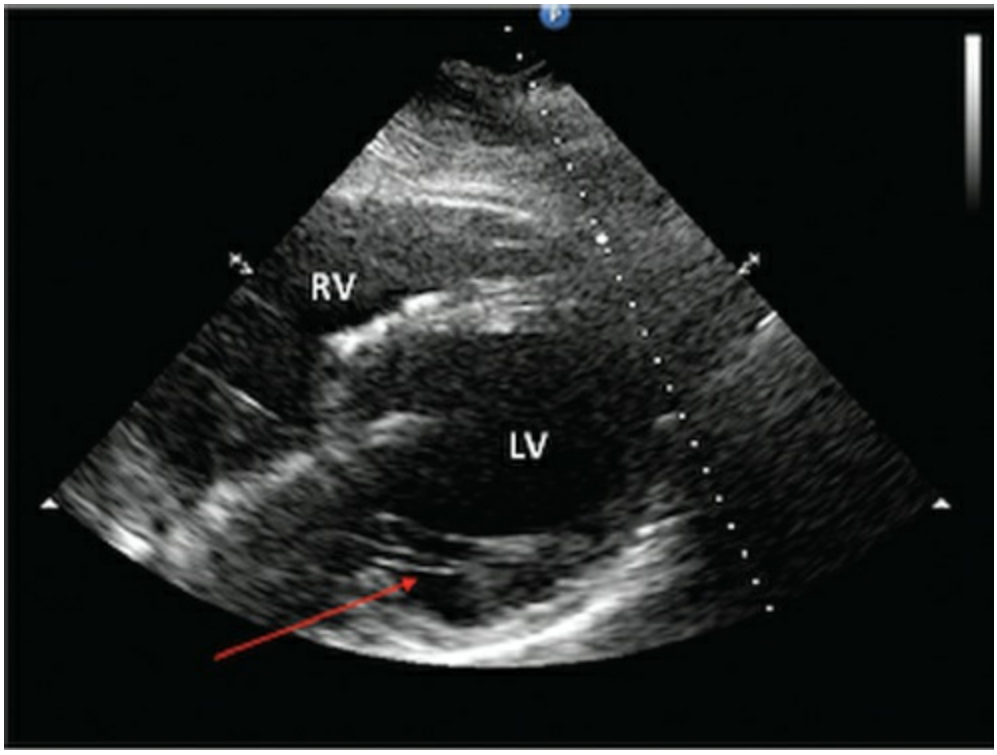


**Figure 151.2.** Focused CUE, subxiphoid view. Of note, this patient's cardiac output is being supported with a percutaneous left ventricular assist device (Impella; Abiomed, Danvers, MA), which is visualized in the left ventricle and indicated by the arrow.

**With sufficient practice, the CUE may be used to (1) identify pericardial or pleural effusion, (2) assess left or right ventricular function, (3) evaluate gross valvular abnormalities, and (4) assess intravascular volume status.** The CUS does not replace comprehensive echocardiographic assessment.

## Ultrasound for Difficult Vascular Access

Using ultrasound for internal jugular (IJ) or femoral vein cannulation is safer, and more efficacious and efficient as compared to the landmark technique, and thus standard of care in many institutions. Advantages of this technique include direct visualization of the intended target and avoidance of neighboring structures such as arteries, nerves, and organs (i.e., apex of the lung). As with any ultrasound-guided procedure, identify surface anatomic landmarks prior to probe placement. The target vessel and adjacent structures are typically identified in a short-axis or cross-sectional view. The depth of the target vessel is then assessed, allowing for an accurate and safe needle trajectory. The tip of the needle should be visualized as it enters the target vessel; then, once the vein has been accessed, proceed with line placement using a Seldinger or modified Seldinger technique. Finally use ultrasound to assess the location and course of the guide wire, exclude injury to neighboring structures, and evaluate for a postprocedural pneumothorax (as described above).

Although less commonly performed, ultrasound-guided cannulation of the subclavian (SC) vein is also possible. A recent study demonstrated a higher success rate, shorter time to successful line placement, and lower complication rate as compared to the landmark technique. Obtain a short axis view of the SC vein inferior to the clavicle at approximately the mid-clavicular line. The probe is then moved laterally and slightly cephalad (part of the probe may contact or overlap the clavicle at this point) until the best simultaneous image of the SC vein and SC artery is obtained (Fig. 151.3), with the pleura appearing as a bright echogenic line inferior to the vessels. The compressibility of the vein and pulsatility of the artery should be apparent. The skin is entered using a long needle at an angle of 30 to 45 degrees. Gently tap or wiggle the needle to help visualize its trajectory. Once the vein is accessed, complete the procedure as described for the IJ approach above.

Finally, ultrasound is a useful adjunct for placing peripheral intravenous lines. Once a vein has been identified, it is imaged in a short- or long-axis view, and the angiocatheter is advanced into the lumen under real-time ultrasound guidance. This technique increases the likelihood of successful cannulation when standard techniques fail.

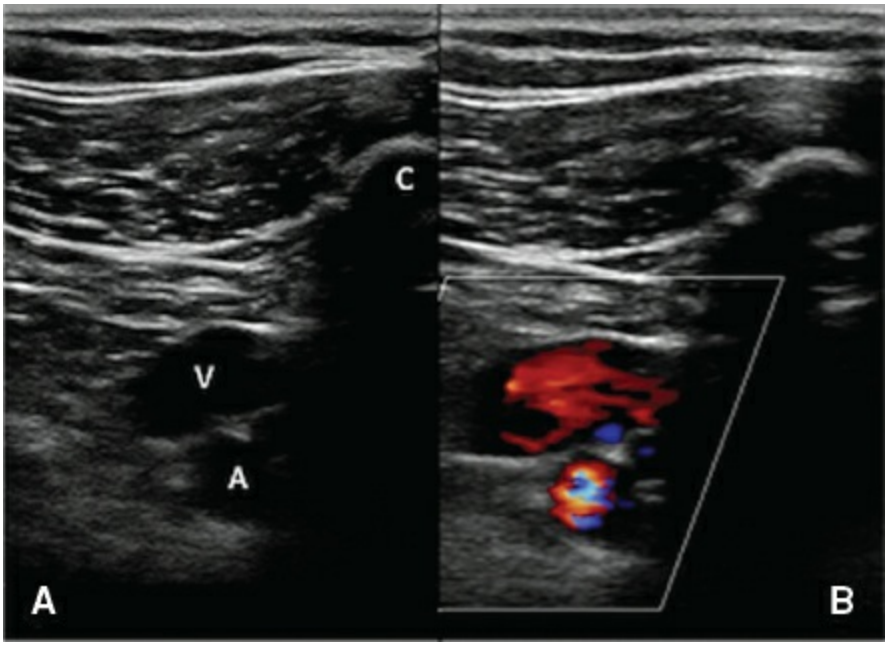


**Figure 151.3. A:** The subclavian vessels imaged with ultrasound. The subclavian vein is seen superior to the subclavian artery. The clavicle appears in the upper right corner of the screen and is identified by its echogenic edge and the dark shadow it casts. **B:** Color flow Doppler is used to identify the opposite flow patterns of the vein (superior) and artery (inferior).

## Summary

Ultrasound is a safe, versatile, portable, and extremely useful adjunct for aiding

diagnosis and guiding therapeutic interventions. Anesthesiologists should become adept at using ultrasound for the indications outlined herein.

## TAKE HOME POINTS

- Focused lung ultrasound is used to assess for pneumothorax, pulmonary edema, consolidation, and pericardial effusion.
- Focused cardiac ultrasound is used for assessing and managing hemodynamic instability.
- Ultrasound is a noninvasive, portable technique that improves the safety and efficacy of many invasive procedures.
- Although less commonly performed than ultrasound-guided internal jugular or femoral cannulation, ultrasound-guided cannulation of the subclavian vein is feasible and likely improves outcomes as compared to the landmark technique.

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# Don’t Overlook the Potential of Perioperative Acupuncture

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As we have noted elsewhere in this book, there is much interest in complementary and alternative medicine (CAM) as perioperative clinicians and anesthesia providers strive to improve perioperative outcomes, shorten length of stay, heighten patient safety, contain costs, and improve perioperative outcomes. There are many types of CAM, including acupuncture, aromatherapy, biofeedback, chiropractic, and herbal medicine. Of these modalities, acupuncture has great promise for the perioperative provider but a central question persists—can it help us meet our goals for enhancing our overall delivery of perioperative services? We believe it can! We are advocates for the adoption and inclusion of acupuncture throughout the spectrum of perioperative clinical care and in the pain clinic as well. For example, the Department of Anesthesia and Perioperative Medicine at Oregon Health and Science University (OHSU) employs six fully-trained acupuncturists, including an anesthesiologist, who provide care for inpatients. All of the six acupuncturists at OSHU are credentialed to do inpatient acupuncture and rotate through the inpatient service. Currently, Medicare doesn’t reimburse physicians providing acupuncture on an inpatient basis but does provide good reimbursement for acupuncturists. Other trained acupuncturists focus on outpatient and pain work. Most of the OHSU anesthesia providers also are credentialed for providing acupuncture to treat postoperative nausea and vomiting.

Acupuncture and the philosophy and practices of Traditional Chinese Medicine from which it arose are not homogeneous practices. And they never were. These modalities have been practiced in Asia for several thousand years and continue to be practiced today. As the practice of acupuncture was passed down through the centuries there were significant regional, cultural, and philosophical differences throughout Asia. This heterogeneity was greatly magnified by the profound upheaval that took place in China in the 20th century. Today, if you lived in a mid-sized Chinese city, the medical care available to you would be an amalgam of TCM, including acupuncture, and “Western”

diagnostic and treatment modalities. And there might be an entirely different mix from the medical treatment available in either the largest Chinese cities or the rural countryside.

## Acupuncture Training—Licensed Acupuncturists Versus Medical Acupuncturists

In the late 1990s, The World Health Organization (WHO) and the World Federation of Acupuncture and Moxibustion Societies (WFAS) published the WHO and WFAS Guidelines on Basic Training and Safety in Acupuncture. These guidelines, which are available online, recommended the minimum requirements in education and training for acupuncture practice based on prior education and the intended application of the acupuncture practice. The guidelines specified four categories:

**Category 1.** People with no prior medical training. (This is for licensed acupuncturists.) = 2000 hours.

**Category 2.** Physicians who want to practice only acupuncture. (This is rare since it implies a physician who would not use any conventional treatments or techniques from their western medical specialty.) = 1500 hours.

**Category 3.** Physicians who want to add acupuncture to their medical specialty. (This is 99% of Medical Acupuncturists.) = Not less than 200 hours.

**Category 4.** Health care personnel who want to specialize in a certain aspect of acupuncture treatment. (This is, e.g., for nurses or social workers who become Acupuncture Detoxification Specialists.) = Hours & requirements are variable depending on specialty and use.

However, these categories and recommendations are not legally binding. Rather, in the United States, the legal requirements for specific acupuncture education and training are determined individually by each state. Most states have requirements that are based on these guidelines, however there is some variability.

The American Board for Medical Acupuncture (ABMA) has proposed national board certification standards for medical acupuncturists as has the NCCAOM for licensed acupuncturists. These standards are also utilized by the various states in their individual licensing requirements.

The ABMA defines medical acupuncture as:

- "Medical acupuncture is a medical discipline having a central core of knowledge embracing the integration of acupuncture from various traditions into contemporary

biomedical practice." and

- "A Physician Acupuncturist is one who has acquired specialized knowledge and experience related to the integration of acupuncture within a biomedicine practice."

In general, to obtain national board certification in acupuncture, physician acupuncturists in the United States must hold an MD or DO degree from the United States or Canada and be board certified in a medical specialty. They must complete 300 hours of education in systematic acupuncture treatment in an ABMA-approved program that is a combination of didactic and clinical exposure. After completion of didactic training, they must have two years of clinical acupuncture experience and compile case histories of 500 clinical acupuncture treatments in at least two acupuncture treatment modalities. They must then pass an exam that is similar to the NCCAOM exam for licensed acupuncturists.

## Efficacy of Acupuncture in the Perioperative Period

Although much work remains to be done before definitive practice guidelines can be reached, there is a growing body of research for the efficacy of acupuncture throughout the perioperative period and in the pain clinic. We have covered the application of acupuncture to prevent and ameliorate postoperative nausea and vomiting, using the P6 point, in Chapter 153. There is also some intriguing work investigating the use of acupuncture as a wellness modality for clinical providers.

## Preoperative Optimization

An interesting use of acupuncture for preoperative carotid endarterectomy was recently reported in the Russian medical literature. A small study found concluded that, "Acupuncture treatment leads to cerebral hemodynamic reserve growth in most patients with significant brachiocephalic stenosis. The inclusion of acupuncture in therapeutic complex improves the quality of preoperative preparation to carotid endarterectomy and its tolerability."

Similarly, there seem to be potential applications for acupuncture in the cardiac surgery rooms. A study by Yang et al. in the Annals of Thoracic Surgery in 2010 reported "that electroacupuncture (EA) pretreatment may alleviate cardiac-reperfusion injury in adult patients undergoing heart valve replacements." This study randomized 60 patients each to an EA pretreatment group or a control group. The intervention group received EA at bilateral Neiguan (PC6), Lieque (LU 7), and Yunmen (LU2) for 30 minutes each day for five consecutive days before surgery. At 6 hours, 12 hours, and 24 hours after reperfusion, levels of serum cardiac troponin I were significantly decreased in the intervention group compared to the control group. Overall serum troponin release

was also decreased at 6 hours, 12 hours, and 24 hours after removal of aortic cross-clamp. Electroacupuncture pretreatment also reduced the inotrope score at 12 hours, 24 hours, and 48 hours after intensive care unit arrival and shortened intensive care unit stay time.

Of course, there continues to be ongoing investigation on the efficacy of acupuncture for preoperative anxiolysis. For example, a 2016 study by Attias et al. found that acupuncture given in conjunction with anxiolysis by pharmacologic agents was superior to the pharmacologic agents given alone.

## Postoperative Pain Control

A 2017 study found that acupuncture had efficacy for posttonsillectomy swallowing pain over a control group who received pharmacologic agents only. In this study, the acupuncture was performed by an investigator who had learned the specific acupuncture points utilized for the intervention group as the study was being designed.

There is great interest in nonpharmacologic modalities to reduce pain after total knee arthroplasty. A 2017 meta-analysis by Tedesco et al., published in JAMA Surgery reviewed and examined several treatment modalities including continuous passive motion, preoperative exercise, cryotherapy, electrotherapy, and acupuncture. Only electrotherapy and acupuncture were associated with any significant efficacy in the amelioration of postoperative pain. Moderate-certainty evidence was found that acupuncture delayed the time to first opioid use and low-certainty evidence was found that acupuncture decreased pain as assessed on POD 2 via visual analog scale. Electroacupuncture has also been reported to reduce postoperative pain after mesh hernia repair and decrease stress hormone levels and anxiety in the postoperative period.

A 2014 study by Ntritsou et al. looked at intraoperative and postoperative EA as an adjunctive therapy to tramadol and ketamine in 75 patients undergoing prostatectomy. The double-blind study randomized participants to receive just tramadol and ketamine or tramadol, ketamine, and acupuncture at the time of closure and just after extubation. The intervention group had electroacupuncture applied at LI4 during closure of the abdominal wall and at ST36 and LI4 just after extubation. The acupuncture group had lower pain scores, decreased in rescue analgesia at 45 minutes and a decrease in postoperative cortisol levels.

## Chronic Pain

In one of the most comprehensive systematic reviews of acupuncture, Vickers et al. (2012) analyzed data from nearly 18,000 patients in randomized controlled trials. They demonstrated that acupuncture improves chronic headaches, neck and back pain,

osteoarthritis, and shoulder pain. Further the evidence showed that there was a significant difference between placebo/sham acupuncture and verum acupuncture. Patients receiving acupuncture had less pain and there was less variability in outcomes than those who received sham acupuncture. In a recent update to their study, Vickers et al. (2018) demonstrated that the improvements in pain only diminished by an average of 15% at 1 year posttreatment.

One of the authors of this chapter (Scott Mist) recently reported results on a randomized controlled trial of group acupuncture versus group education for women with fibromyalgia. While it is a preliminary study, compared to the education group, group acupuncture had improved global symptom impact (43%), pain (45%), and fatigue (33%). He also found that the intervention was safe and well-tolerated. Vas et al., (2016) demonstrated a similar effect (41% pain reduction) using individualized treatments over 10 weeks.

When applied to temporomandibular disorders there is evidence that acupuncture is more effective than placebo in reducing pain intensity in TMD. Fernandes et al. (2017) and Ritenbaugh et al. (2008) found that acupuncture produced a 32% reduction in average pain at 3-months posttreatment. In a follow-up analysis, Elder et al., (2012) demonstrated that participants in the study also had significant reduction in pain medications even though medication reduction was not a focus of the study and was never discussed with participants.

## Wellness for Providers

In March 2018, Buchanan et al. reported on health care providers who underwent a series of five auricular acupuncture sessions during a 16-week period utilizing a published protocol for treating emotional trauma. Participants reported significant decreases in state and trait anxiety and increases in work engagement.

A small study of 10 medical students reported decreased pre-exam anxiety after treatment with auricular acupuncture.

## Safety

Overall acupuncture is generally a safe treatment modality. The best safety study to date is provided by Witt et al. (2009). In 2009, a prospective observational study of over 200,000 patients who received an average of 10.2 treatments reported that 8.6% of patients reported at least one adverse event. The most common reported adverse event was bleeding or bruising. It is common in practice that the withdrawal of a needle is accompanied by a drop of blood or a local bruise. Pain during needling was also a common effect (2%). The most severe safety issues are pneumothorax caused by needles inserted too deeply and infection. The rate of pneumothorax has not been well

established but in the Witt et al. study there were 2 cases and a large retrospective study in South Korea, Kim et al., 2016 the incidence was estimated at 0.001%. For comparison, 7 in 100,000 males and 1 in 100,000 females will experience spontaneous pneumothoraces. Rodgers-Fischi et al., 2017 Witt et al. demonstrated that the infection rate was approximately 0.014% and all cases were quickly remedied. It is interesting and important to note these safety estimates given that the acupuncturists in the study had only received an average of 140 hours of training, far less than the training received by diplomate acupuncturists.

## TAKE HOME POINTS

- Acupuncture is an ancient healing modality originating as a modality within the practice of Traditional Chinese Medicine.
- There is a growing body of research on its use in the perioperative period, although more studies are needed.
- It has been suggested that acupuncture may provide significant preoperative physiologic optimization for patients undergoing both vascular and cardiac surgeries.
- Acupuncture may be a viable modality for the treatment of preoperative anxiolysis.
- Acupuncture has been reported to decrease pain scores, use of rescue analgesia, and postoperative cortisol levels.
- At least one study has demonstrated that a course of preoperative electroacupuncture improved perioperative parameters such as troponin levels and inotrope scores in patients undergoing cardiac valve replacement and also decreased length-of-stay in the intensive care unit.
- There are emerging data on the use and efficacy of acupuncture in chronic pain conditions such as fibromyalgia, temporomandibular joint disorders, low back and neck pain, osteoarthritis, and shoulder pain.
- Acupuncture is a very safe treatment modality with the most common side effects of bruising, bleeding, and soreness.
- We recommend that anesthesia providers take whatever opportunities are available to obtaining training and credentialing in acupuncture and to include this very promising treatment modality into their perioperative practice.

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# Consider Acupuncture as an Adjunct for the Prophylaxis and Treatment of Postoperative Nausea and Vomiting

Scott D. Mist, PhD MAcOM LAc Dipl. NCCAOM, Kristin King Liao, LAc Dipl. NCCAOM, Albert Liao, LAc Dipl. NCCAOM, and Leena Mathew, MD

Unfortunately, postoperative nausea and vomiting (PONV) is still a common side effect of anesthesia despite the availability of newer-generation antiemetics and shorter-acting anesthetics and opioids. PONV is one of the two most significant factors leading to patient dissatisfaction (the other, of course, being pain). The incidence of PONV is approximately 70% in those patients who are at high risk for this complication and 30% in the general population. Even though postoperative vomiting is self-limited, it can cause significant morbidity, including dehydration, wound dehiscence, aspiration, and electrolyte imbalance. PONV also increases costs since each episode of emesis in the postanesthesia care unit (PACU) delays discharge by an average of 20 minutes.

The following factors place a patient at high risk for PONV:

) **Patient-related factors:** Female, nonsmoking, dehydrated, and with prior episodes of PONV.

) **Procedure-related factors:** Ear, nose, or throat surgery, intra-abdominal surgery, laparoscopic surgery, strabismus repair, intracranial surgery, and obstetric or gynecologic surgery. A 30-minute increase in the duration of surgery increases the baseline risk for PONV by 60%. Any surgical procedure needing large fluid administration can cause gastrointestinal edema, which can also increase the incidence of PONV.

) **Anesthesia-related factors:** The use of volatile agents, nitrous oxide, neostigmine (more than 2.5 mg) and long-acting opioids.

At present, the most common modalities for the prophylaxis and treatment of PONV include ensuring adequate, but not excessive, hydration; avoidance of risk factors; and the use of pharmacologic agents, such as metoclopramide, dexamethasone, and 5 HT3

antagonists. **Acupuncture is an additional approach that shows great promise in prophylaxis and treatment of PONV.** In 1997, a National Institutes of Health Consensus Development Panel on acupuncture reviewed the available evidence from randomized controlled trials and concluded that clear evidence indicates that needle acupuncture is efficacious for postoperative and chemotherapy-related nausea and vomiting and probably also for pregnancy-related nausea.

Americans are now spending approximately $27 billion annually on complementary and alternative medical treatments. Statistical reports published as early as 1997 suggest that visits to complementary practitioners outnumber those to conventional practitioners by 12 to 1. Acupuncture is only one of many complementary and alternative modalities, but it is one that is already somewhat familiar to patients. A great degree of integration exists between "standard" medical techniques and acupuncture in the East, especially in China, and there is now a growing recognition of the need for such integration in the Western health system.

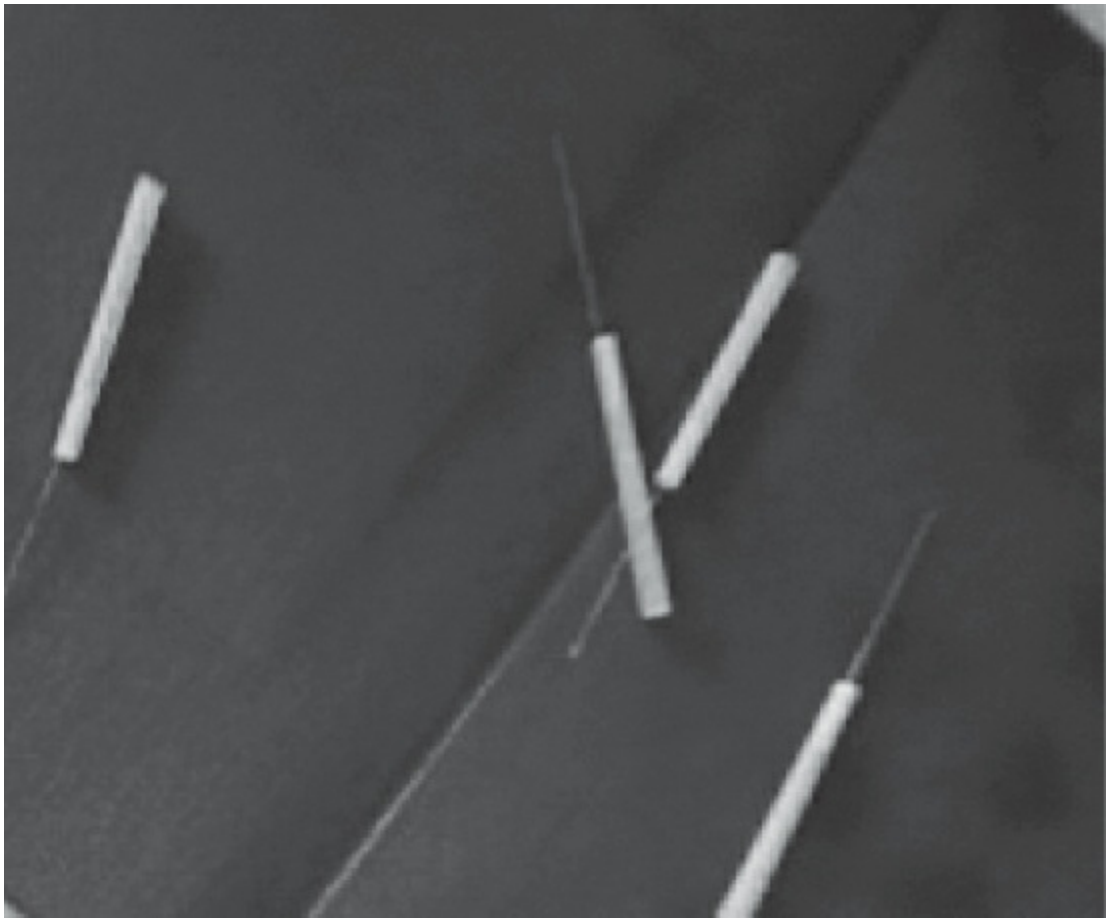

**Figure 153.1.** Stainless-steel acupuncture needles.

To review briefly, acupuncture is accomplished by stimulating acupoints. There are 14 major meridians corresponding to internal organs, along which there are a total of

365 acupoints. Acupuncture involves the placement of fine, disposable, stainless-steel needles (Fig. 153.1) at select acupuncture points. Acupuncture needles range from 1/4 inch to several inches in length and a few thousandths to several thousandths of an inch in diameter. One inch and 1.5 inch are the most commonly used lengths of needle. The vast majority of needles used in the United States are of stainless steel; rarely, copper, gold, silver, or titanium also are used. The placement of needles may be followed by a stimulation technique done to the needle to elicit a characteristic sensation called De Qi, although there is ongoing discussion in the acupuncture community about the necessity and technique for eliciting De Qi at the P6 point. Stimulation may be done by manual twirling or electrical stimulation but can also be done by laser or by moxibustion. Moxibustion involves the burning of fine herbs to apply gentle heat at the free end of the needle. The choice of specific needle stimulation technique, if any, depends upon the therapist's experience, preference, and patients' concerns and condition. In our private practice, we do not follow an absolute rule that it is necessary to elicit De Qi in the stimulation of the P6 point. Manual acupuncture involves manipulating the inserted needles by lifting, thrusting, twisting, twirling, or doing other complex combinations. It is a traditional method of acupuncture and is most commonly used in clinical practice.

Electroacupuncture (EA) is achieved by attaching the acupuncture needles to an electrical-pulse generator and stimulating the acupoints with electrical pulses. EA appears to be more consistent and to generate more reproducible results, and it is more efficacious than manual acupuncture. The procedure for EA is to insert the acupuncture needle as would normally be done and then attach an electrode to the needle to provide continued stimulation. The benefits of using electrical stimulation are absence of prolonged hand maneuvering, reduction of total treatment time by providing continued stimulus, and better control of the frequency of the stimulus.

As recently as 20 years ago, there were scant data to define the mechanism of action of acupuncture in terms of "Western" physiology and pathophysiology. That is definitely not the case today as there are a growing number of reports on the mechanisms of manual acupuncture and EA. For example, an important review in 2014 by Ruixin Zhang et al., published in 2014, summarized the effects of acupuncture on persistent pain. They summarized the current findings:

"In the last decade, preclinical investigations of electroacupuncture mechanisms on persistent tissue-injury (inflammatory), nerve-injury (neuropathic), cancer, and visceral pain have increased. These studies show that electroacupuncture activates the nervous system differently in health than in pain conditions, alleviates both sensory and affective inflammatory pain, and inhibits inflammatory and neuropathic pain more effectively at 2–10 Hz than at 100 Hz. Electroacupuncture blocks pain by activating a variety of

bioactive chemicals through peripheral, spinal, and supraspinal mechanisms. These include opioids, which desensitize peripheral nociceptors and reduce pro-inflammatory cytokines peripherally and in the spinal cord, and serotonin and norepinephrine, which decrease spinal n-methyl-d-aspartate receptor subunit GluN1 phosphorylation. Additional studies suggest that electroacupuncture, when combined with low dosages of conventional analgesics, provides effective pain management that can forestall the side effects of often-debilitating pharmaceuticals."

Acupuncture also decreases gastric-acid secretion and promotes forward peristalsis. It was previously thought that administration of naloxone reversed the analagesic effects, however currently there are a couple of studies that show low dose naloxone actually increases the efficacy of acupuncture for pain.

Many studies indicate that acupuncture at the P6 acupuncture point is effective in ameliorating postoperative nausea and also nausea and vomiting associated with chemotherapy and pregnancy. Acupressure at P6 has also been shown to be antiemetic, and there is fairly extensive literature on the use of P6 acupressure for treating pregnancy-related nausea and vomiting. This point is specifically designated in traditional Chinese medicine for the treatment of vomiting.

The Neiguan or P6 acupoint is located along the pericardial meridian on the volar aspect of the forearm, 2 Cun proximal to the distal wrist crease and approximately 1 to 1.5 cm below the surface of the skin. It lies in between the tendons of the flexor carpi radialis and palmaris longus (Fig. 153.2). A Cun is a unit of traditional Chinese medicine measurement. Cun are proportional distances and not absolute measurements, so one Cun is approximately equal to the middle finger's middle interphalangeal distance. But, for Western medicine-trained clinicians, the definitive locations is 1/6 the distance between the distral wrist crease to the cubital crease between the flexor carpi radialis and the palmaris longus tendons.

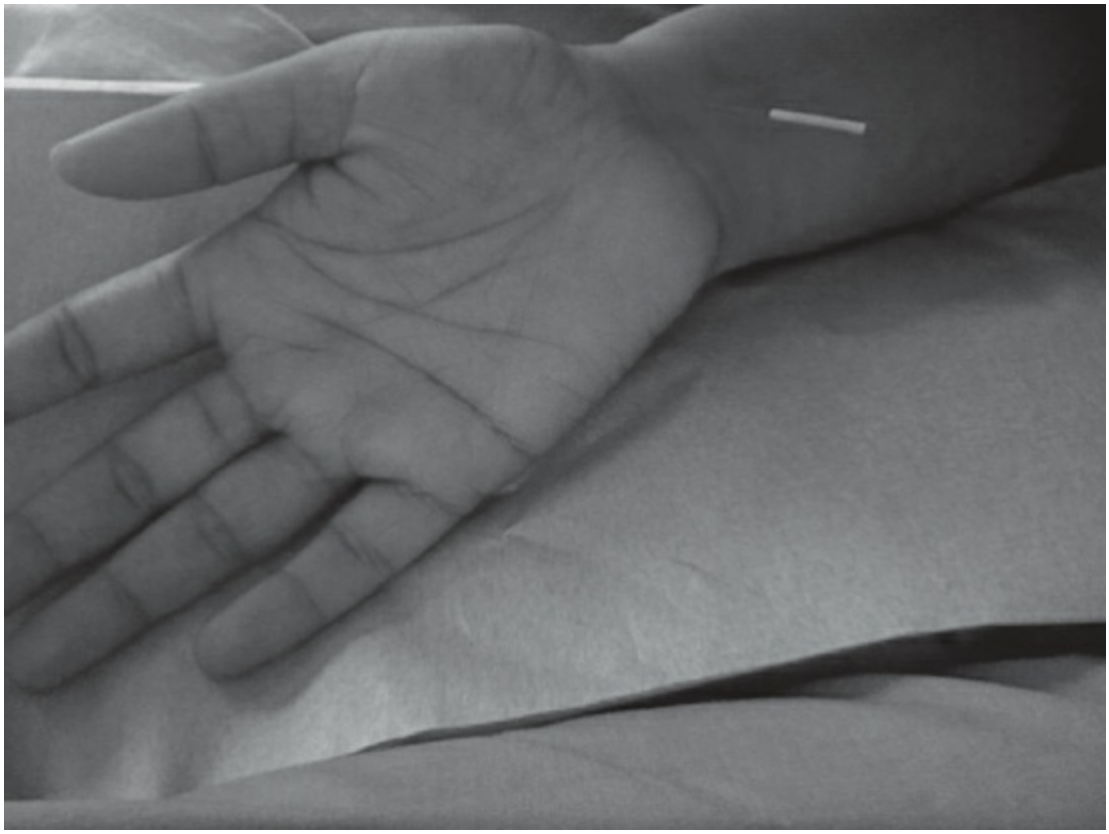

**Figure 153.2.** P6 point.

Prophylaxis of PONV by acupuncture is more efficacious than treatment of PONV by acupuncture and involves the placement of bilateral P6 needles. These needles are inserted in a sterile fashion immediately after induction of anesthesia and are kept in place for 15 to 30 minutes. If patient positioning or operation timing precludes this, the acupuncture may be done in the postoperative recovery unit after surgery. The needles can then be manually or electrically stimulated. In our personal practices, we like to do this a few treatments prior to surgery along with ST36 and SP6 if the Zhangfu diagnosis and preoperative schedule accommodate it. If not, we recommend focus on the appropriate treatment including PC6. Acupressure may also be applied by the application of "sea bands," which do not have the same degree of efficacy as acupuncture; however, placement is easily done and does not require professional training.

Previous studies of pediatric patients having tonsillectomy reported that acupuncture was unsuccessful in preventing or treating PONV. However, in these studies, only a unilateral P6 point was used without uniformity in the exact location of P6 as 2 Cun above the wrist. Recently, this has been contradicted, with a randomized double-blind study with 120 tonsillectomy patients by Moen et al. showing that acupuncture at P6 bilaterally and CV13 provided similar antiemetic effect to dexamethasone. A second study found that intraoperative application to the P6 point for 20 minutes was associated

with an antiemetic effect not experienced by control patients who did not receive intraoperative antiemetic acupuncture treatment. Most importantly, a 2016 meta-analysis in the journal Laryngoscope reviewed eight articles and found that acupuncture at the P6 was associated with a significant reduction compared to control groups, with a risk ratio of 0.77. In adult patients, Dundee performed a series of well-designed studies, including prospective, randomized, sham-controlled trials. These studies provided reliable evidence on the efficacy of acupuncture in treating PONV by TEAS at PC6 as an adjuvant to antiemetic use in more than 100 patients in whom chemotherapy-induced sickness was not adequately controlled by antiemetic use alone. In a randomized, controlled trial with concealed allocation, sham control, and careful blinding, EA was found to control emesis effectively in 104 patients with breast cancer receiving chemotherapy. In a recent single-blinded study involving 593 women with early pregnancy, nausea was significantly reduced with acupuncture at P6 alone. No side effects have been reported to date, other than local soreness at the site of needle placement.

The mechanism of acupressure or acupuncture at P6 to prevent PONV is not completely understood. Because the P6 point is located near the median nerve, stimulation of this point has been postulated to release neurotransmitters that desensitize the chemo trigger receptor zone (CTZ) and thus prevent nausea and vomiting. However, once the CTZ is sensitized, it is difficult to desensitize it. Accordingly, for prophylaxis of PONV, it may be better for acupuncture to be done after induction of anesthesia but before emergence.

Because of its anatomic accessibility and efficacy in preventing PONV, we feel that this acupuncture practice is well within the range of all anesthesia providers who wish to provide this clinical technique to their patients. At one of our editor's institutions (Oregon Health and Science Institute) the administration provides access to training and proctoring to all providers who request it. The faculty are then given limited acupuncture privileges for the sole purpose of treating and preventing PONV.

## TAKE HOME POINTS

- Acupuncture is an excellent adjunct with minimal side effects in the treatment and prophylaxis of postoperative nausea and vomiting. It is more effective in the prophylaxis than in the treatment of PONV.
- It is now generally accepted that acupuncture at the P6 point has antiemetic efficacy in both adult patients and pediatric tonsillectomy patients.
- The P6 point is stimulated bilaterally by acupuncture with manual or electrical stimulation or acupressure.
- Placement of the needles can be done after before or after induction of anesthesia or

in the PACU.

- The mechanism of action of acupressure or acupuncture at P6 is not completely understood.
- Some providers have had good results with "sea bands," which can be applied by the nursing staff.
- Consider, inquire, or request training, proctoring, and limited privileges for acupuncture treatment of P6 for treatment of PONV if such is available at your institution.

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# Don't Warm Up a Cardiac Arrest Patient Unless They Are Dying of Hemorrhage!

Admire Kuchena, MD and Michael P. Hutchens, MD MA

In 2005, the American Heart Association included therapeutic hypothermia (TH) in the Advanced Cardiac Life Support therapy recommendations for out–of-hospital cardiac arrest. TH is the cooling of body temperature below that required for normal physiologic functions to 32° to 34°C. This is achieved by either surface or endovascular cooling, or in some instances cardiopulmonary bypass. Earlier studies published in 2002 had shown significant improvement in neurologic outcome and survival in patients with return of spontaneous circulation treated with TH within 6 hours following out-of-hospital cardiac arrest. Patients in the control group had no intervention specifically geared toward temperature control and this was associated with poor survival and neurologic outcome.

However, these protocols have recently been called into question by a multicenter, randomized trial which compared 33°C to 36°C, and found no difference in outcome. This study suggested that avoidance of fever may be more important than hypothermia. "Temperature Management" rather than TH may be a more appropriate term allowing for control of temperature below normal physiologic temperatures, but above traditional TH ranges.

## How Does Therapeutic Hypothermia Provide Neuroprotection?

The complex mechanisms by which TH protects the brain and improves survival are largely unelucidated. The chain of events that follows ischemia and cellular injury is accelerated by fever and inhibited by hypothermia. It is speculated that TH provides neuroprotection through suppression of immune inflammatory response, inhibition of neuronal apoptosis, minimizing oxidation/reduction reactions, and attenuation of neuronal cell metabolism.

**Suppression of immune response and inflammation.** Poor cerebral perfusion during cardiac arrest results in brain injury. Proinflammatory molecules such as

interleukin 1, interleukin 6, interleukin 8, tumor necrosis factor, and transforming growth factor beta are produced in excessive amounts by endothelial cells, astrocytes, and microglia. These molecules have been implicated in leukocyte chemotaxis to sites of injury, phagocytosis by macrophages as well as activation of the complement system. This results in additional neuronal damage. Studies in animal models have demonstrated that production of these molecules is suppressed by inducing TH.

**Inhibition of apoptosis**. TH potentially rescues cells in the early stages of apoptosis. Following low perfusion states, injured cells undergo the apoptotic pathway of programmed cell death. Hypothermia at 33°C was demonstrated to reduce morphologically detected apoptotic neuronal cells by 50% to 70% in mice models.

**Decreased free radical production.** With return of spontaneous circulation, reperfusion results in production of oxygen-free radicals (peroxide, hydrogen peroxide, hydroxyl radicals, peroxynitrite), which can potentiate "reperfusion injury" in cells of the brain and other organs. These charged molecules cause loss of cell membrane integrity, proteolysis, DNA damage, and ultimately cell death. Specifically on the brain, free radicals disrupt the blood–brain barrier resulting in cerebral edema, increased intracranial pressure, and central nervous system dysfunction. At lower temperatures, there is significant reduction in the quantity of free radicals.

**Reduced cerebral metabolism.** Cerebral metabolism increases during periods of stress following brain injury. This results in increased oxygen demand, consumption, and production of carbon dioxide. Higher oxygen demand increases cerebral blood flow, intracranial pressure, and cerebral edema. TH reduces cerebral metabolism. For every 1°C drop in core body temperature, cellular metabolism is reduced by 5% to 7%.

## Potential Complications of Therapeutic Hypothermia

**Coagulopathy**. Hypothermia at <35°C results in platelet dysfunction and at <33°C results in low platelet count and disruption of the coagulation cascade. This anticoagulation effect of TH in itself provides neuroprotection, but does increase the risk of bleeding. Pay meticulous attention to patients who are actively bleeding or undergoing surgery at the time of cardiac arrest before applying TH. In high-risk patients, initiate surgical or medical correction and control of bleeding before treatment with TH. Also, targeted temperature control may be a preferred route for this patient population.

**Infections**. The increased risk of infection associated with TH remains controversial. Some speculate that TH potentially increases infection risk by suppressing host's response to infection, creating limitations for the clinician to diagnose, and treat infection. The use of invasive interventions such as central venous catheters, mechanical ventilation, and TH-induced cutaneous vasoconstriction which

impairs wound healing postoperatively, can increase infection risk. Minimize infection risk by limiting TH to 24 hours, being deliberate about looking for possible infection with frequent thorough physical examinations and cooling patients to 36°C instead of 33°C. Due to the challenge of diagnosing an infection while undergoing either TH or targeted temperature management (TTM), it may be reasonable to have a lower threshold to obtain screening cultures, and starting empiric antibiotics in high-risk patients. Best practices including catheter-associated infection prevention bundles, frequent repositioning of patients to avoid pressure points can reduce the risk for a hospital-acquired infection.

**Cardiac arrhythmias**. Hypothermia can result in bradycardia due to decreased firing by cardiac pacemaker cells, prolonged duration of action potentials, and decreased conduction through the myocardium. If bradycardia results in significant reduced cardiac output, heart rate should be augmented by external pacing (transvenous or transcutaneous) or chronotropic pharmacologic agents. Tachycardia during TH is most commonly caused by inadequate sedation or shivering. In euvolemic patients who are protected from shivering by sedation and analgesia, hypothermia increases myocardial contractility. In addition to bradycardia, other EKG changes include increased PR interval, wider QRS complex, and the presence of Osborne waves (J waves or camel hump waves commonly seen in lateral and precordial leads with the height being proportional to degree of hypothermia). Response to antiarrhythmics and cardiac defibrillation can be decreased during TH.

**Shivering**. The human body tightly regulates core body temperature through several thermoregulatory mechanisms. Shivering is one of the two primary autonomic responses to cold, with arteriovenous shunt vasoconstriction being the second one. Shivering increases myocardial and overall oxygen consumption, cellular metabolism, work of breathing, and heart rate. In patients with cardiomyopathy, increased myocardial oxygen demand and consumption increases the risk of further cardiac events. Mitigate shivering with appropriate sedation, analgesia, and paralysis during TH. If clinically appropriate, use agents such as fentanyl, meperidine, dexmedetomidine, propofol, magnesium, and clonidine.

**Insulin resistance**. The amount of insulin secreted by the pancreas and sensitivity to insulin are both decreased during hypothermia. In critically ill patients, this can result in hyperglycemia which is a known physiologic response to stress. Unfortunately, in critically ill patients, hyperglycemia is associated with worse outcomes stemming from sepsis, respiratory failure, polyneuropathy, acute kidney injury, and poor wound healing. Adverse effects of hyperglycemia result from direct glucose toxicity, disruption of mitochondrial respiration, impairment of macrophage and neutrophil function, and endothelial dysfunction. Thus, higher doses of insulin may be required during TH. At the

same time, the care team needs to be vigilant during rewarming as insulin sensitivity and secretion increase to avoid rebound hypoglycemia.

**Electrolyte abnormalities**. Hypothermia is associated with renal tubular dysfunction, increased electrolyte excretion, and intracellular shift of electrolytes. Low levels of magnesium, potassium, and phosphate have been reported. Magnesium is neuroprotective, hypophosphatemia is associated with increased infection risk, and hypokalemia may result in hemodynamically significant arrhythmias. During electrolyte replacement, the risk of hyperkalemia during rewarming can result in potentially fatal arrhythmia.

## TAKE HOME POINTS

- TH improves neurologic outcome and survival following cardiac arrest. Neuroprotection is mediated through suppression of immune inflammatory response, inhibition of neuronal apoptosis, minimizing oxidation/reduction reactions, and attenuation of neuronal cell metabolism.
- Mitigate modifiable risk factors for adverse effects in TH or TTM.
- The benefits and risks of TH should be weighed in post cardiac arrest patients. If no contraindications, employ target temperature management following cardiac arrest.
- Keep electrolytes at low end of normal and avoid over retreatment of hypokalemia. Slow rewarming instead of rapid rewarming can prevent potential fatal rebound hyperkalemia.
- TH can increase infection risk by suppressing the host's response to infection, creating barriers for clinicians to promptly detect and diagnose infection, its use of invasive catheters and mechanical ventilation, and impairing wound healing.
- In actively bleeding patients or patients with a coagulopathy, weigh the benefit and risk before employing TH and consider surgical or pharmacologic treatment of bleeding.
- Treat with opiates, sedatives, and paralytics as needed to reduce shivering during TH.

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# What to Do If You Get a Needlestick Injury

Maria C. Lanzi, MS MPH ANP-BC COHN-S and Sarah Foster-Chang, DNP APN-BC COHN-S

In 1991, the Occupational and Safety Administration (OSHA) published the Bloodborne Pathogen Standard, Title 29 Code of Federal Regulations, Part 1910.1030 to protect workers from bloodborne illnesses. Needlestick injuries are a major cause of these exposures in health care settings. OSHA estimates that 800,000 needlestick injuries occur annually among health care workers in the United States, with nurses being the most frequently injured. There are limited data regarding specific occupational hazards to anesthesia personnel. Greene et al. in a multicenter study, reported 1.35 contaminated needlestick injuries per 1,000 anesthetics administered, or 0.54 per 1,000 hours of anesthesia.

While needlestick injuries in the health care setting have been associated with the transmission of up to 20 bloodborne pathogens, the most serious are human immunodeficiency virus (HIV), hepatitis C virus (HCV), and hepatitis B virus (HBV). Despite well-publicized institutional protocols for reporting needlestick injuries and the ready availability of postexposure prophylaxis and medical follow-up for health care workers, research demonstrates that underreporting continues to be a significant problem. In one report, a surprising 60% to 95% of house staff failed to report needlestick injuries. Residents and attending physicians reported only 29% and 19% of needlestick and percutaneous injuries, respectively. Surveys of anesthesiology residents and attending physicians revealed significant underreporting as well. In the United States, only 45% of anesthesia personnel who suffered a needlestick injury sought treatment. Although needlestick injuries may be individually detrimental and potentially life-threatening, the underreporting of these injuries diminishes the accuracy of population data regarding disease transmission rates and unnecessarily increases the risk of bloodborne pathogen transmission to health care workers.

## Common Scenarios Associated With Needlestick Injuries

Needlestick injuries may occur any time a needle is exposed. Engineering and

technology have dramatically increased the safety of needle use, but these advances represent only one component of accidental needlestick prevention. Examples of safety features include built-in safety devices, such as needle shields, retractable needles, safety catheter encasement devices, and needleless intravenous (IV) delivery systems. The majority of contaminated needlestick injuries in anesthesia personnel are preventable.

However, accidental needlestick injuries continue to occur despite these advances in technology. These injuries most commonly occur during certain situations:

- During clean-up after use (such as starting an IV, phlebotomy)
- If sharps are disposed of improperly
- If a needle is being recapped
- While manipulating the needle in the patient
- While passing a device to another health care worker during or after use
- While handling or transferring specimens
- During collision with a sharp or with a health care worker handling the sharp
- Between steps of a multistep process

Some needlestick injuries are considered to be "high risk." These include injuries from hollow-bore needles, needles that are contaminated with blood, and needles that are blood-filled. Anesthesiology personnel are especially susceptible to the above high-risk situations. Prevention of needlestick injuries involves vigilance on the part of personnel handling sharps. Most injuries have been shown to arise from the use of needles attached to syringes, suture needles, hollow-bore needles, IV catheter–needle stylets, and epidural needles. One multicenter study reported that 59% of all injuries, 68% of injuries from the use of hollow-bore needles, and 78% of high-risk contaminated percutaneous injuries were preventable.

## Human Immunodeficiency Virus

In the United States, the risk of HIV transmission to health care workers after percutaneous exposure to HIV-infected blood has been estimated at approximately 0.3%. The transmission rate varies based on the seroprevalence of the patient population. Projections cite the 1-year risk of an anesthesia provider contracting HIV from occupational exposure at 0.00013% to 0.3%, and the 30-year risk to be from 0.0038% to 0.94%.

Several factors have been associated with an increased risk of HIV transmission from a patient to a health care worker as a result of a needlestick injury. These factors include an increased quantity of blood transferred during the exposure, use of a larger-bore needle (gauge larger than 18), deep injury, a device visibly contaminated with the patient's blood, exposure during a procedure that involved placing a needle into a

source patient's vasculature, or exposure to a source patient in the terminal stage of acquired immunodeficiency syndrome (AIDS). The immunologic status of the exposed health care worker also plays a role in determining risk.

Symptoms of primary or acute HIV infection are generally nonspecific, resemble flu-like symptoms, and can occur within days or weeks of the initial exposure. They typically include fever, rash, malaise, pharyngitis, lymphadenopathy, and headache. Some people experience severe symptoms after contracting HIV, whereas others experience no symptoms whatsoever. Given the nonspecificity of symptoms, the only reliable method of diagnosing HIV infection is antibody testing, with an FDA-approved antigen/antibody combination immunoassay that detects HIV-1 antibodies, HIV-2 antibodies, and HIV-1 p24 antigen. No further testing is required if the initial screen is negative.

There is evidence that immediate postexposure prophylaxis is associated with decreased risk of transmission, mainly in animal models. Factors influencing the risk of transmission in those models include viral load, interval between exposure and the start of therapy, duration of therapy, and selection of antiretroviral regimen. The data available on human subjects are far less extensive. A retrospective case-control study conducted by the Centers for Disease Control and Prevention (CDC), specifically on health care workers, indicated an 81% reduction in HIV transmission risk with postexposure treatment with zidovudine. More current multidrug regimens are believed to be even more effective. According to the CDC, no proven HIV transmissions after occupational exposure have been reported since 1999. Current postexposure prophylaxis regimens include at least three antiretroviral agents, raltegravir 400 mg twice daily, tenofovir DF 300 mg once daily, and emtricitabine 200 mg once daily. Although chemoprophylaxis may provide benefit, it is not without risk or side effects. Adverse effects range from mild symptoms such as nausea, diarrhea, and headache to more severe effects such as neutropenia, neuropathy, and hepatotoxicity. Newer medications, in particular raltegravir, tenofovir, and emtricitabine have a much safer and less toxic side effect profile than HIV prophylactic medications used in the past. If a source is HIV positive, alternative regimens may be indicated, but only in conjunction with expert consultation. HIV treatment is complicated by drug resistance and the drug regimen must be prescribed carefully based on the clinical history and status of the source patient.

## Hepatitis B Virus

HBV is much more commonly transmitted via needlestick injuries than HIV, with transmission rates ranging from 2% to 40%, depending on the hepatitis B antigen status and infectivity of the source patient. Hepatitis B transmission rate has significantly

declined over the last 20 years, both due to recommended hepatitis B immunization among health care workers and the addition of hepatitis B immunization as a recommended childhood immunization at birth. Factors associated with the risk of transmission include the source patient's hepatitis B surface antigen titers, the extent of infectivity, and the degree of contact with the source patient's blood.

Hepatitis B immunity is conferred by documented, appropriately given three-dose history and a positive titer post completion of the third dose. In some instances, a second series of three doses may be recommended to result in a positive titer. The duration of immunity conferred by the vaccination is believed to be somewhere between 10 and 31 years depending on the immune response of the recipient and age at administration. And although hepatitis B surface antibody titers may wane, since hepatitis B immunization is a B-cell–mediated immunity, immunity is ensured by the presence of a previously positive titer after completion of a three-dose series. Effectiveness of the hepatitis B immunization is influenced by a number of factors, including immunocompromise, obesity, advanced age, smoking history, improper vaccination storage, and improper vaccine administration. Immediately after a needlestick injury or any other accidental exposure, all health care workers should be evaluated for immunity.

Symptoms of acute HBV infection occur in one-third to one-half of infected people. These symptoms include jaundice, fever, nausea, and abdominal pain. The majority of acute infections resolve, but chronic infection may develop in 5% to 10% of infected people. One in five patients who develop chronic hepatitis B infections has a risk of developing liver cirrhosis, while 6% of chronically infected people may die from liver cancer.

Postexposure prophylaxis with hepatitis B immune globulin and hepatitis B vaccine is >90% effective in preventing HBV transmission. Postexposure prophylaxis with HBV immune globulin and HBV vaccinations are based on the exposed health care worker's vaccination history, immunity response to previous vaccinations, and serum anti-HBsAb titers. HBV immune globulin, if needed, should be given within 7 days of exposure, as efficacy may decline if treatment is postponed. HBV vaccine should be given at the same time.

Health care workers who are vaccinated against HBV should be tested 1 to 2 months following the last dose of primary vaccination to evaluate immunity. If they receive immune globulin, immunity testing will need to be postponed until 4 to 6 months later.

With appropriate postexposure treatment, transmission of HBV is unlikely. In the event a health care worker is infected with hepatitis B and the disease becomes chronic, effective treatment is now available via direct-acting antivirals. Up-to-date treatment protocols are available through the American Association for the Study of Liver

Diseases (AASLD) website listed in the references section.

## Hepatitis C Virus

The rate of transmission of HCV has not been well established, but the prevalence of HCV in health care workers is slightly higher than in the general population. The annual incidence of acute infections of HCV is approximately 2% to 4% in health care workers who have a history of occupational exposure to blood, such as with a history of needlestick injuries. The 1-year risk of an anesthesia provider contracting HCV via occupational exposure ranges from 0.00084% to 0.21%, and the 30-year risk ranges from 0.025% to 6.12% based on HCV seroprevalence in the patient population. Among anesthesia personnel in the United States, an estimated 5.18 HCV infections are expected to occur per year. The incidence of anti-HCV seroconversion after accidental percutaneous exposure to HCV is approximately 1.8%, with transmission occurring primarily with the use of hollow-bore needles.

Symptoms of acute hepatitis C infection range from fever, jaundice, and malaise to fulminant hepatic failure. Many patients are asymptomatic during the acute phase, but may have elevated liver transaminases. Up to 75% to 85% of acute hepatitis C cases will progress to chronic hepatitis, with a smaller proportion of chronic patients developing cirrhosis or hepatic cancer. Given the nonspecificity of symptoms, HCV antibody testing must be performed to confirm the diagnosis.

Unlike HIV and HBV, at the present time, there is no vaccine to prevent HCV and no recommended postexposure prophylactic regimens. However, the development and use of a variety of direct-acting antivirals and new noninvasive techniques to assess liver status (Fibroscan) have changed the hepatitis C treatment landscape. Treatment is individualized based on genotype and liver disease status. Newer direct-acting antivirals, including ledipasvir/sofosbuvir (Harvoni) and sofosbuvir/velpatasvir (Epclusa), have pan-genotype coverage, offer once a day dosing, and significantly reduced side effect profiles. (See Table 155.1.)

**Table 155.1 ■ Direct-Acting Antivirals for Treatment of Hepatitis C**

| Class | Approved Agents (Genotypes) | Mechanisms of Action | Barrier to Resistance |
|---|---|---|---|
| NS3/4A protease inhibitors | Grazoprevir (1,4)<br>Paritaprevir/ritonavir (1,4)<br>Simeprevir (1,4) | Blocks active site of protease enzyme | Intermediate to high |

| | | | |
|---|---|---|---|
| NS5A inhibitors | Daclatasvir (1–6)<br>Elbasvir (1,4)<br>Ledipasvir (1,4,5,6)<br>Ombitasvir (1,4)<br>Velpatasvir (1–6) | Blocks viral replication complex, particle assembly, and release | Low to intermediate |
| NS5 B nucleoside inhibitors | Sofosbuvir (1–6) | Blocks NS5B active site; inhibits RNA elongation | High |
| NS5B nonnucleoside inhibitors | Dasabuvir (1) | Blocks NS5B allosteric site; incudes conformational changes | Low |

Note: Newer drugs (released in 2016 and 2017) have coverage for all genotypes 1–6 and are combination drugs (Harvoni and Epclusa).

Derived from Perales C, Quer J, Gregori J, et al. Resistance and hepatitis C virus to inhibitors: Complexity and clinical implications. Viruses. 2015;7(11):5746–5766; Poordad F, Dieterick D. Treating hepatitis C: Current standard of care and emerging direct acting antiviral agents. J Viral Hepat. 2012;19(7):449–464.

If a health care worker is concerned about possible exposure to HCV, the CDC recommends two possible approaches. Initial screening is done in both protocols to establish the health care worker baseline status. A hepatitis C antibody screen is done and if negative, it may be assumed the health care worker's initial hepatitis C status is negative. At 3 weeks or more postexposure, a hepatitis C RNA PCR (viral load) test may be ordered.

Another approach is to perform a hepatitis C antibody at 4 months and only perform a hepatitis C RNA PCR (viral load) if the hepatitis C antibody screen is positive. A negative hepatitis C antibody at 4 months postexposure would also indicate infection did not occur.

| Test Outcome | Interpretation | Further Actions |
|---|---|---|
| **HCV antibody nonreactive** | No HCV antibody detected | Sample can be reported as nonreactive for HCV antibody. No further action required. If recent exposure in person tested is suspected test for HCV RNA[a]. |
| **HCV antibody reactive** | Presumptive HCV Infection | A repeatedly reactive result is consistent with current HCV infection, or past HCV infection has resolved, or biologic false positivity for HCV antibody. Test for HCV RNA to identify current infection. |
| **HCV antibody reactive, HCV RNA detected** | Current HCV infection | Provide person tested with appropriate counseling and link person tested to care and treatment[b]. |
| **HCV antibody reactive, HCV RNA not detected** | No current HCV infection | No further action required in most cases.<br>If distinction between true positivity and biologic false positivity for HCV is desired and if sample is repeatedly reactive in initial test, test with another HVC antibody assay.<br>In certain situations[c] follow up with HCV RNA testing and appropriate counselling |

[a]If HCV RNA testing is not feasible and person tested is not immunocompromised, do follow-up testing for HCV antibody to demonstrate seroconversion. If the person tested is immunocompromised, consider testing for HCV RNA.

[b]It is recommended before initiating antiviral therapy to retest for HCV RNA in a subsequent blood sample to confirm HCV RNA positivity.

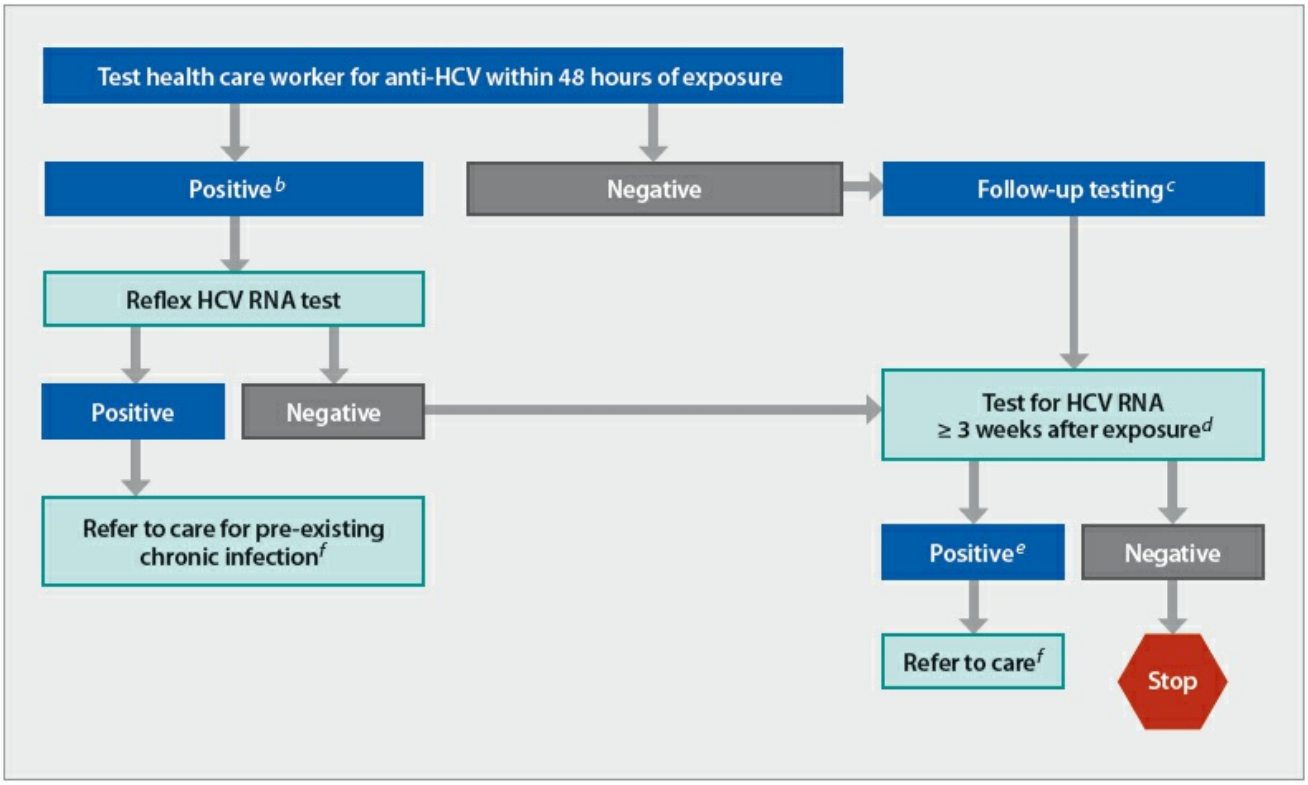
[c]If the person tested is suspected of having HCV exposure within the past 6 months, or have clinical evidence of HCV disease, or if there is concern regarding the handling or storage of the test specimen.

# Information for Health Care Personnel Potentially Exposed to Hepatitis C Virus (HCV)

## Recommended Testing and Follow-up

Exposure to viral hepatitis has long been recognized as an occupational risk for health care personnel, with recommendations previously established for the management of occupational exposures to hepatitis C virus (HCV). This notice, which is based on current laboratory guidance[1], updates the 2001 HCV testing algorithm for health care personnel[2]. Postexposure prophylaxis (PEP) of hepatitis C is not recommended, as outlined in the 2001 MMWR on management of health care personnel who have occupational exposure to blood and other body fluids[2].

Test the source for HCV RNA[a]. If the source is HCV RNA positive, or if HCV infection status unknown, follow the algorithm below. After a needlestick or sharps exposure to HCV-positive blood, the risk of HCV infection is approximately 1.8%[2]. If the health care worker does become infected, follow AASLD/IDSA guidelines (www.hcvguidelines.org) for management and treatment of hepatitis C.




[a]If it is not possible to test source for HCV RNA, then test for antibodies to HCV (anti-HCV) and screen HCW exposed to anti-HCV positive source. Note that persons with acute infection may test HCV RNA positive but anti-HCV negative.

[b]In a nationally representative population sample with low (1%) HCV infection prevalence, 22% of anti-HCV positive results were determined to be false-positive. An additional 10% had indeterminate results in a confirmatory assay; most were likely to be false-positive. Among the subset of persons testing anti-HCV screening reactive and subsequently HCV RNA negative, 50% of the anti-HCV tests were false-positive.[3]

[c]Anti-HCV testing at >= 6 months with reflex to HCV RNA test, if positive, could also be done.

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*Continued on next page*

[d]A single negative HCV RNA test using currently available FDA-approved tests in the US (all with lower limit of detection <100 IU/mL in serum)[4] is considered sufficient to rule out chronic HCV infection when screening an HCV antibody-positive individual with no known ongoing risk of exposure. HCV RNA becomes detectable within 3 weeks after exposure even when the antibody is still undetectable. Persons who develop symptoms of acute HCV infection such as jaundice may be tested earlier than 3 weeks, but if negative would require re-testing at ≥ 3 weeks. Spontaneous clearance of acute infection may occur up to six months after exposure, therefore persons testing HCV RNA positive < 6 months after exposure should be tested again at ≥ 6 months to determine infection status.

[e]All patients with current HCV infection as evidenced by a positive HCV RNA test result should be evaluated by a practitioner with expertise in assessment of liver disease severity and HCV treatment. Guidance for hepatitis C treatment may be found at www.hcvguidelines.org and is changing rapidly with the advent of new therapies.

[f]Spontaneous clearance of infection may occur up to six months after exposure; persons testing HCV RNA positive < 6 months after exposure should be tested again at ≥ 6 months after exposure to determine infection status.

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[1] CDC. Testing for HCV infection: An update of guidance for clinicians and laboratorians. *MMWR Morb Mortal Wkly Rep*. 2013; 62(18): 362–365

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[3] Moorman A, Drobenuic J, Kamili S. Prevalence of false-positive hepatitis C antibody results, National Health and Nutrition Examination Study (NHANES) 2007-2012. *J Clin Virol*. 2017; 89: 1–4.

[4] FDA Executive Summary, Prepared for the March 21-22, 2018 meeting on the Reclassification of HIV and HCV Diagnostic Devices Joint Panel Meeting of the Blood Products Advisory Committee and the Microbiology Devices Panel of the Medical Devices Advisory Committee. Table 3: FDA Approved HCV RNA Tests for the Detection of HCV RNA in HCV Antibody Positive Individuals, Table 4: FDA Approved HCV RNA Tests for the Quantitation of HCV in Anti-HCV Positive Individuals. Available from https://www.fda.gov/downloads/AdvisoryCommittees/CommitteesMeetingMaterials/BloodVaccinesandOtherBiologics/BloodProductsAdvisoryCommittee/UCM598744.pdf
Accessed April 27, 2018.

If the baseline hepatitis C antibody screen is positive, a confirmatory hepatitis C RNA PCR (viral load) is always done to confirm the diagnosis. If a health care worker is determined to have a pre-existing hepatitis C infection (prior to the work-related exposure) it is important to determine the genotype and viral load. A health care worker may be infected with a different or additional hepatitis C genotype. If on repeat testing at 3 weeks, which would include a hepatitis C RNA PCR (viral load) and genotype determination, a health care worker with a pre-existing hepatitis C infection is also infected with a new genotype related to a specific work exposure, treatment would be individualized for that individual.

Spontaneous clearance of acute hepatitis C infection may occur up to 6 months after exposure, so persons testing HCV RNA positive <6 months after exposure should be tested again at ≥6 months to determine infection status. All patients with current HCV infection as evidenced by a positive HCV RNA test result should be evaluated by a practitioner with expertise in assessment of liver disease severity and HCV treatment.

Current treatment/practice guidelines are available via the AASLD website: https://www.aasld.org/publications/practice-guidelines-0. Treatment choices and duration depend on hepatitis C genotype, patient clinical circumstances, and history of treatment.

## TAKE HOME POINTS

- Needlestick injuries expose health care workers to bloodborne pathogens that can cause potentially fatal diseases. The three pathogens of most concern are HIV, HBV, and HCV.
- Advances in technology and the engineering of safety devices have dramatically reduced the incidence of needlestick injuries. Needlestick injuries are grossly underreported by physicians, especially house staff. Unreported needlestick injuries could have devastating personal consequences and also prevent the precise calculation of transmission and seroconversion rates.
- Effective treatment of hepatitis B and hepatitis C is now available, but the treatment for HIV currently still requires life-long management.
- Prevention is the best defense against needlestick injuries. Avoid risky behaviors such as needle recapping and transferring of specimens, pay attention to proper sharps disposal, and avoid using nonsafety needles or other nonsafety sharps if an alternative with built-in safety controls is available.
- Needlestick injuries should always be reported. Immediate evaluation and treatment of blood and body fluid exposures results in the best outcomes for the health care worker.

## Suggested Readings


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## SECTION VIII

# REGIONAL ANESTHESIA

156

# Introduction

Raymond G. Graber, MD

It is an exciting time in the field of regional anesthesia. The use of ultrasound guidance has allowed us to develop and master new approaches. We have the capability of improving patient care by providing better analgesia, decreasing narcotic use and coincident narcotic side effects. But as with any procedure, lurking behind the benefits are the potential risks, side effects, and complications. It is fun and rewarding to perform regional anesthesia techniques, but if you aren't aware of the risks and how to deal with them, you should not be utilizing these techniques. Because as satisfying as regional anesthesia can be, the potential complications can be catastrophic. In the following chapters, multiple authors will try to light the way for you on your regional anesthesia journey. You will read about ways to improve your techniques, avoid the pitfalls, and deal with complications.

Where do we need to go from here? We need to continue to develop blocks and analgesic strategies that minimize side effects and complement surgical goals of early ambulation and physical therapy. It is not good enough to just provide excellent analgesia. We need to strive to provide it in ways that doesn't reduce mobility, impair respiration, cause urinary retention, or impair the patient in any other way. Some examples: There's a move toward using adductor canal blocks rather than femoral blocks for total knee replacement, so as to better preserve quadriceps function. Combined axillary and suprascapular nerve blocks are being investigated as an alternative to interscalene block for shoulder surgery, because this combo does not have the risk of phrenic nerve dysfunction like interscalene block does. We are also awaiting on further studies to define the utility, safety, and appropriate use of long-lasting local anesthetics such as lipid-encapsulated bupivacaine. Another issue to keep on your radar is the continuing development of novel anticoagulants, and the as yet to be defined safe use of neuraxial anesthetics around them.

We hope you enjoy the following chapters, and that they help guide and improve your everyday practice. OK, let's be safe out there!

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# Complications of Regional Anesthesia: Don't Touch the Needle Before You Know Them

David A. Burns, MD, Brian T. Gierl, MD, and Raymond G. Graber, MD

## Introduction

Regional anesthesia provides pain relief that makes patients happy and it reduces length of stay that makes both patients and hospital administrators happy. Regional anesthesia techniques have been developed to safely provide analgesia for many different procedures and conditions and these techniques are often being applied to patients with multiple comorbidities, which increases both the risk and severity of complications. This chapter discusses some of these risks and how to minimize them.

## Infection

Regional anesthesia is minimally invasive, but is it still invasive! Anytime that a needle is inserted through the dermis there is a risk of infection. That risk is further increased if a peripheral nerve catheter is left in situ, because now there is a conduit that bypasses the protective barriers of the skin. Infections can occur when the needle is introduced through contaminated skin or a tissue infection. Nerve block catheters can be colonized by skin flora or by hematologic spread and result in either local infection or an abscess. An epidural abscess is especially problematic, and will cause significant morbidity or mortality.

- Factors predisposing toward infection:
  - Immunocompromised states
    - Immunosuppression
    - Steroid use
    - Diabetes
    - Sepsis or concurrent infection
  - Extended duration of use
  - Sterile technique not employed

- Techniques for avoiding infection:
  - Sterile preparation of the site—allow the chlorhexidine to dry
  - Aseptic technique
  - Sterile occlusive dressings
- Techniques for avoiding or limiting gross contamination:
  - Limit duration or tunnel the catheter (or both).
  - Avoid placement through sites of infection.
  - Administer a dose of antibiotics before placement of invasive lines or nerve-block catheters in patients with sepsis. Studies of placement of such lines and catheters have shown that the risk of infection with bacteremia is reduced to baseline if administration of antibiotics has been started before placement. Therefore, you should carefully weigh the risks and benefits of the technique and make sure an appropriate antibiotic has been given within one hour of the start of the procedure.
  - Limit breaks in tubing for bag changes. Every time the integrity of the tubing system is violated by reservoir changes, contamination of the local anesthetic solution is possible—limit such opportunities for contamination.
  - Follow the patient daily and inspect for signs of infection, including erythema, pus, tenderness at the site, and fever.
- Treatments for infection:
  - If infection is suspected, remove the catheter. Usually such removal leads to avoidance or resolution of infection, unless the patient is immunocompromised.
  - Ensure that the patient is receiving appropriate antibiotics.
  - Continue to follow the patient's case to ensure resolution of infection.
  - In the case of suspected epidural abscess, speed of diagnosis and treatment is of the essence to avoid permanent neurologic injury.

## Bleeding

Many major peripheral nerves travel adjacent to major blood vessels (e.g., axillary, infraclavicular, supraclavicular, femoral, popliteal fossa, sciatic). Many are deep locations at which applying direct pressure would be difficult or impossible (e.g., epidural, spinal, classic paravertebral, infraclavicular, supraclavicular, lumbar plexus). Because the epidural space has an extensive venous plexus, bleeding can easily be caused by epidural or spinal anesthesia. An expanding hematoma in the fixed, enclosed epidural space can cause spinal cord compression and paralysis.

- Techniques for avoiding bleeding:
  - While placing the block, maintain continuous aspiration for blood.
  - If you are proficient in ultrasound techniques, use visualization of the vessels in real time with the passage of the needle to avoid vascular puncture and to place the local

anesthetic more precisely.

- Obtain a careful history to ascertain if a patient is on preoperative blood thinners. Also, discuss with your surgeons whether there is a plan to put patients on blood thinners postoperatively.
- The American Society of Regional Anesthesia and Pain Medicine (ASRA) has made recommendations regarding the safe performance of neuraxial blocks when patients are on anticoagulants before or after surgery. Three editions have been published, and work is underway on a fourth edition. These recommendations should be followed for neuraxial blocks and deep peripheral nerve blocks. The recommendations are summarized in Table 157.1. These guidelines are updated periodically, and are easy to find on the ASRA website. The third edition ASRA guidelines did not include recommendations for many of the newer anticoagulant drugs that have recently come to market. While work continues on the full fourth edition, ASRA has posted draft-recommended time intervals before and after neuraxial block or catheter removal for some of these drugs. (See Table 157.2.)
- In the patient with normal coagulation, bleeding complications rarely cause clinical morbidity.

**Table 157.1 ■ ASRA Guidelines Summary**

**Heparin**

- 5,000 U BID SC dosing: No contraindication
- >10,000 U SC/day: Unclear risk; possible prothrombin time (PT) elevation in some patients (may be helpful to check activated clotting time [ACT])
- If greater than 4 days of heparin, check platelet count to rule out heparin-induced thrombocytopenia
- Intraoperative IV heparinization: Delay heparin for 1 hr after needle insertion
- Removing catheters: Wait 2–4 hrs after last dose or infusion stopped and check ACT or partial thromboplastin time (PTT); then, pull catheter; restart heparin 1 hr after catheter removal

**LMWHs**

- Preoperative prophylactic dose: Wait 10–12 hrs after last dose (enoxaparin 30 mg q12h or enoxaparin 40 mg SC qd)
- Preoperative treatment dose: Wait 24 hrs after last dose (enoxaparin 1 mg/kg q12h or enoxaparin 1.5 mg/kg qd)
- Postoperative prophylactic dose BID dosing: First dose greater than 24

hrs postoperatively; epidural catheters removed before initiation; first dose at least 2 hrs after removal of epidural catheter
- Postoperative prophylactic dose single daily dosing: First dose 6–8 hrs postoperatively; second dose 24 hrs later; catheter removal more than 10–12 hrs after a dose, but more than 2 hrs prior to next dose; thus, about a 10-hr window to remove catheter

**Warfarin**
- Preoperatively: Stop warfarin 4–5 days prior to the procedure and check the international normalized ratio (INR); INR less than or equal to 1.4 is acceptable
- Postoperative warfarin: Remove catheters when INR is less than 1.5; if INR is 1.5–3, remove with caution and do not remove if concurrent antiplatelet or other antihemostatic agents are in use; perform frequent neurologic checks—If INR is greater than 3, hold warfarin

**Antiplatelet drugs**
- NSAIDs: No contraindication to neuraxial block
- Clopidogrel (Plavix): Wait 7 days after last dose (5 days may be acceptable if normalization of platelet function can be shown)
- Ticlodipine (Ticlid): Wait 14 days after last dose
- Patients taking GP IIb/IIIa inhibitors: abciximab (ReoPro)—wait 48 hrs after discontinued; eptifibatide (Integrilin) or tirofiban (Aggrastat)—wait 8 hrs after discontinued

This table is a summary of the recommendations from Horlocker TT, Wedel DJ, Rowlingson JC, et al. Regional anesthesia in the patient receiving antithrombotic or thrombolytic therapy: American Society of Regional Anesthesia and Pain Medicine evidence-based guidelines (third edition). Reg Anesth Pain Med. 2010;35(1):64–101.

**Table 157.2 ■ Preliminary ASRA Recommendations for New Anticoagulants**

| Drug | Time Before Puncture, Catheter Manipulation, or Removal (days) | Time After Puncture, Catheter Manipulation, or Removal (hrs) |
|---|---|---|
| Dabigatran | 5 | 6 |
| Apixaban | 5 | 6 |
| Rivaroxaban | 3 | 6 |

| | | |
|---|---|---|
| Prasugrel | 7–10 | 6 |
| Ticagrelor | 5–7 | 6 |

These preliminary recommendations are posted on the ASRA website: https://www.asra.com/advisory-guidelines/article/1/anticoagulation-3rd-edition.

## Nerve Damage

The incidence of nerve damage after use of a regional block is reported to be between 0.04% and 5%. The vast majority of these are dysesthesias that last less than a week. It is more common to damage a nerve by many means that are unrelated to the regional anesthetic but are coincidental in their timing. Nerve damage may result from surgical stretch or trauma, retractor use, excessive pressure from tourniquet use, or excessively long tourniquet time. Poor positioning, leading to tension, stretch, or compression, can occur either in the operating room or during the postop period. Tight casts and bandages can also cause compression issues. Although use of a regional anesthetic often is initially blamed for nerve damage, only careful investigation will lead to the true cause.

Theoretically, use of a regional block can damage the nerve in the following ways: the needle may cut the nerve; an intraneural injection may mechanically disrupt the nerve; an intraneural injection with high pressure may cause ischemia; additives like epinephrine may cause intense vasoconstriction; and, finally, neurotoxicity of the solutions may damage the nerve.

Techniques for avoiding nerve damage:

- Avoid using deep sedation and general anesthesia during placement. If the patient cannot tell you reliably whether he has pain upon injection or has a paresthesia, you have lost that safety monitor. (However, our pediatric brethren feel differently about this. A moving, squirming pediatric patient may increase the risk of injury during a block, so it is common practice to do pediatric regional techniques under deep sedation or general anesthesia.)
- By the same logic, consider avoiding “rescue” or supplemental blocks because the patient’s ability to feel pain of paresthesia is diminished.
  - Stop if the patient has pain upon injection. Intraneural injection may cause pain in the distribution of that nerve.
- Although there are scant data to prove that intraneural injections pose more risk, most experts would recommend avoiding these practices. Dr. Bigeleisen believes that small volumes of intraneural injection is so safe that he has had the procedure performed on himself! However, we avoid the practice of seeking paresthesias or using ultrasound guidance to place a needle intraneurally … Safety First!
- Avoid injecting local anesthetic when the twitch threshold current is less than 0.2 mA.

(Twitch threshold current is the current at which the muscle twitch is lost when the nerve stimulator is dialed down.) Because current density is proportional to the distance squared, avoiding needle placement that results in a motor response with a current of less than 0.2 mA is widely believed to prevent intraneural injection. However, be aware that a threshold current greater than 0.2 mA does not guarantee safety. An animal study where needles were on purpose placed intraneurally demonstrated that threshold currents can be much higher than 0.2 mA, thus shredding this long-held dogma.

- Use short-beveled/blunt needles. Such use is widely thought to reduce the likelihood of cutting the nerve.
- Use low pressure to inject. If there is resistance to injection, the needle may be placed intraneurally. An injection pressure monitor is available and on the market for those who want to be more scientific about this.
- Remember that the neurotoxicity of all local anesthetics increases with increasing concentration. If an intraneural injection occurs, the higher the concentration, the worse the potential damage.
- Use ultrasound guidance. Ultrasonographic visualization of the nerves and the needle allows you to reduce the risk of poor positioning. Be aware that ultrasound guidance is not perfect. It is very common to be able to see the needle, but not necessarily the needle tip. The tip may be out of plane if the transducer and needle are not perfectly parallel to each other. It is good practice to inject a tiny amount of local anesthetic (.5 ml or less) to verify tip location. (This is of course, after you aspirate.)

## Allergic Reactions

Allergic reactions to regional anesthetics are extremely rare. The ester local anesthetics are hydrolyzed to para-aminobenzoic acid (PABA), which can be allergenic. Patients can sometimes be allergic to a preservative—such as methylparaben (which is metabolized to PABA) or metabisulfite. If a patient has a true allergy to one class of local anesthetic, it is generally safe to use a drug from the other class instead (preservative free preferred). Another common scenario to be aware of is reactions in the dental office. Some patients believe they had an allergic reaction, when in truth they got tachycardic from epinephrine in the local anesthetic. It is important to get a detailed history of the events when a patient states they have a local anesthetic allergy.

## Blockade of Other Nerves

Since we frequently use significant local anesthetic volume in our block injections, there is potential for local anesthetic to spread to other nearby nerves. A prime example of this is interscalene block, where local anesthetic can spread to the phrenic nerve (causing hemidiaphragmatic paresis), to the recurrent laryngeal nerve (causing

hoarseness), and to the sympathetic chain (causing Horner syndrome). These complications are poorly tolerated in patients with poor respiratory reserve or contralateral, recurrent laryngeal nerve palsy. Complications can also occur due to epidural spread from paraneuraxial techniques like the interscalene, paravertebral, or lumbar plexus blocks. In addition, the femoral nerve can become blocked with a field block for an inguinal hernia.

## Intravascular Injection and Local Anesthetic Toxicity

This complication and its treatment are addressed in Chapter 168.

## Supplies and Equipment That Should Be Available When Doing Regional Anesthesia

- Airway equipment: Laryngoscope blades, endotracheal tubes, a suction device, a self-inflating bag, a mask, and a source of oxygen. Do not visit a patient on the floor for a preoperative nerve block without this equipment being present!
- Emergency drugs: epinephrine, atropine, propofol, succinylcholine, benzodiazepines
- 100 mL of 20% Intralipid, especially if using bupivacaine

### TAKE HOME POINTS

- Always use sterile technique when performing regional anesthesia techniques. Don't put neuraxial needles through infected sites. Be wary of putting catheters of any type in patients who are septic.
- Know the ASRA guidelines for regional anesthesia techniques in the patient who is on anticoagulation therapy. (Or, at least know where to look them up!)
- Avoid intentional paresthesias and intentional intraneural injections. Use lower concentrations of local anesthetics, and inject with low pressures.
- Know the common side effects of all your blocks.
- Be prepared to deal with local anesthetic toxicity.

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# Make Time for a Timeout Before Placing a Block—the Preprocedure Check

Mark J. Baskerville, MD JD MBA MA and Jeffrey R. Kirsch, MD FASA

In the perioperative realm, preprocedural timeouts have become a standard of care. By facilitating a pause in the midst of complex and dynamic patient care, preprocedural timeouts have been shown to reduce errors and improve patient safety—especially when coupled with a checklist. Moreover, The Joint Commission mandates a Universal Protocol focused on preprocedure verification, site marking, and a final confirmatory timeout. This timeout must be conducted immediately before any procedure where instruments will be inserted into the body or the integrity of the skin will be compromised. Realize that a wrong-site block is a "never event"—it should **never happen**. Also realize that when things start to go wrong, they often go very wrong; when a highly talented and experienced practitioner blocks the wrong location, the patient seems to also suffer permanent long-term harm of some type.

When placing a nerve block for regional anesthesia, it is **critical** that the anesthesiologist confirm the correct procedure with the correct drug for the correct patient. Other important considerations include the presence of pre-existing neurologic deficits, the use of anticoagulant and antiplatelet agents, and the need for sedation. A checklist should be utilized in a systematic manner from identification of the patient via two distinct means (e.g., patient and wrist band), throughout block preparation, and to final verifications at the timeout. If a patient receives multiple blocks that occur at different times or in different positions, each requires a separate timeout. Finally, the performance of the timeout should be documented in the medical record.

There are situations wherein the anesthesiologist provides primary identification of the patient as well as the surgical site.

- A surgeon usually provides care to a coherent patient that he has met before. However, an anesthesiologist may not have that luxury in today's health care environment where "efficiency" is overemphasized; he or she might complete a nerve block on a patient with Alzheimer dementia prior to the arrival of the orthopedic surgeon. Thus, the anesthesiologist would be responsible for site marking based on

their own exam and review of medical records.

- Realize that a wrong-site nerve block could easily lead to surgical staff prepping the wrong side and a surgeon performing a wrong-site procedure.

Lawsuits following wrong-site surgeries often include all members of the perioperative care team. In one case, the Rhode Island Department of Health's, Board of Medical Licensure and Discipline reprimanded the nurse anesthetist and circulating nurse along with the surgeon for participating in a wrong-site surgery (https://www.ri.gov/press/view/8239).

## Suggested Elements of a Preprocedure Block Checklist

| | |
|---|---|
| Patient identification | Anticoagulation or antiplatelet use |
| Allergies | Equipment/Trays/Ultrasound |
| NPO status | Labeled medications and solutions |
| Surgical procedure | Positioning and aseptic precautions |
| Specific block and technique | Monitoring, oxygen, and IV access |
| Consent | Sedation plan |
| Correct site and side | Resuscitation equipment and drugs |

## Suggested Script for a Timeout

"Attention everyone! All eyes on me."

"This is (patient name), which I have verified with the patient and the patient's identification band. We will perform the following regional anesthesia with (type of block) and the correct side/site is marked."

"Please confirm completion of the Block checklist." (Recite checklist)

"In the event of an emergency, rescue supplies are readily available (confirm) and I will assign the following roles…." (Assign roles)

"Does anyone have any additional questions or concerns?"

## What Should Happen When the Worst Happens?

We here in Portland have not had a wrong-site event since the institution of the preprocedure checklist. But, what if you were faced with such a truly awful situation? As physician executives for our department and institution, here is what we ourselves would do and what we would instruct our staff to do:

) Accept that you have committed what is essentially a legally indefensible act. Don't try to minimize it or hide it. You have to face this one straight on and accept the consequences.

) Call risk management and your departmental leadership up to and including your chairperson.

) Start evaluating whether it is safe to immediately move forward with clinical care and block the correct side. In the days before the routine use of ultrasound-guided blocks, we very often used the maximum dose of anesthetic for the block. These days, it is possible that there may still be room under the maximum dosing guidelines to repeat the block at the correct location. Do not exceed the maximum dosage guidelines for the local anesthetic being used.

) If you do not feel that you can immediately redo the block, then you will have to wait to do your regional anesthetic and case. This is generally when the first block is resolving which may be several hours. We would still try to do everything possible to get the surgery done that same day, in the interest of service recovery for the patient. It is really difficult for many patients to take care of all of their personal issues (i.e., take time off from work, arrange for boarding of a pet, child care, etc.). So, if you have made an error and negated all of the patient's logistical effort, you will likely have a much angrier patient. This could require that the surgeon rearrange their schedule and the ORs will run later than desired. But, if you need to rearrange or extend the OR schedule, so be it.

) Apologize to the patient/family after surgery, when all of the effects of the sedation/GA had resolved.

) Participate fully in the revision and initiation of protocols and review processes that will ensure that it never happens again.

) Recognize that your leadership will work with risk management group work with the patient/their family on a financial settlement that would be linked with their agreement to not initiate legal action.

## TAKE HOME POINTS

- The Joint Commission has declared wrong-site procedures as "never events." A preprocedural timeout to confirm the correct patient and block site is a safety check to prevent such errors.
- The regional anesthesia block team should consistently employ a universal protocol

or checklist during the timeout.

- All members of the procedural team—including the patient, if possible—must participate to ensure a mutual agreement of what is to be done.
- Support staff should be empowered to withhold equipment or trays until verification of the checklist and mutual engagement with a timeout.

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# Chlorhexidine: Killing Bacteria … and Allergic Patients?

Levana Amrock, MD and Brandon Michael Togioka, MD

Your 68-year-old male patient with a history of CHF is presenting for lumbar laminectomy. After a seemingly routine induction, his systolic blood pressure matches his age despite boluses of vasopressors and fluid. Your point of care echocardiogram shows appropriate filling and contractility. What is the etiology?

Chlorhexidine is a topical cationic biguanide with powerful antimicrobial properties against gram-negative and gram-positive bacteria (including multidrug-resistant organisms), biofilms, fungi, and some viruses. At physiologic pH, chlorhexidine salts dissociate, releasing cations that bind to and destabilize bacterial membranes. It is active for at least 48 hours, making it the preferred antiseptic. In high concentrations it is bactericidal (bacteria killing) and in low concentrations it is bacteriostatic (inhibitors of bacterial reproduction). Chlorhexidine's antimicrobial efficacy is well established and it is on the World Health Organization's list of essential medicines.

Due to its proven efficacy, the number of health care and domestic products containing chlorhexidine has dramatically increased over the past 30 years. It is now contained in some central lines, urinary catheters, skin antiseptic preparations, creams/ointments, mouth washes, shampoos, and body washes (Table 159.1). Many patients are completely unaware of their chlorhexidine use at home. In routine anesthesia care, chlorhexidine is commonly used for skin disinfection prior to neuraxial techniques, and arterial line and central line placement. Chlorhexidine is generally preferred over povidone-iodine as randomized controlled trials have shown a reduced rate of catheter colonization with skin flora when chlorhexidine is used.

## Hypersensitivity

The first case of chlorhexidine-induced anaphylaxis was reported in 1984. While not nearly as common as perioperative allergic reactions to neuromuscular blocking agents

or antibiotics, chlorhexidine may be responsible for over 5% of Immunoglobulin E (IgE)-mediated reactions in the perioperative period (Table 159.2). In addition, some experts have suggested that the incidence of chlorhexidine allergy among health care workers and patients will parallel its increased use in the health care and domestic setting. The FDA has documented 52 cases of severe chlorhexidine-induced anaphylaxis; and as of 2017 now requires manufacturers of over-the-counter chlorhexidine products to add an allergy warning to the drug facts label.

Chlorhexidine has been shown to cause a variety of hypersensitivity reactions ranging from mild contact dermatitis to life-threatening anaphylaxis. Anaphylaxis is a type I IgE-mediated hypersensitivity reaction. Once formed, IgE binds surface receptors on mast cells and basophils resulting in the immediate release of histamine, tryptase, and other inflammatory mediators.

**Table 159.1 ■ Common Chlorhexidine-Containing Products**

| |
|---|
| Central venous lines |
| Urinary catheters |
| Surgical skin preparations |
| Surgical dressings and mesh |
| Hand gels |
| Lubricating gels |
| Contraceptives |
| Eye gels |
| Contact lens solutions |
| Mouthwashes |
| Toothpastes |
| Creams/ointments |
| Acne products |
| Body wash |
| Shampoo |
| Cosmetics |

In contrast, contact dermatitis is a delayed type IV cell-mediated hypersensitivity

reaction. Symptom onset is often delayed 48 to 72 hours and requires T-cell activation and proliferation. Notably, there are case reports of patients with a clear history of type IV contact dermatitis with positive chlorhexidine patch testing who subsequently experienced anaphylaxis. Few allergens are known to stimulate both types of allergic response. It is therefore imperative that clinicians recognize that even mild contact dermatitis may indicate a potential for a severe type I hypersensitivity reaction.

## Risk Factors

Some studies have shown that older males are more likely to be diagnosed with a chlorhexidine allergy, which runs counter to data showing that the majority of perioperative anaphylaxis occurs in women. It is controversial whether atopy is a risk factor for chlorhexidine allergy. Some articles have cited an increased incidence of delayed type hypersensitivity to chlorhexidine in atopic patients. On the other hand, atopy is notably absent from most case reports describing chlorhexidine allergy. Most patients with true IgE-mediated chlorhexidine allergy will have a history of mild skin reaction upon previous exposure. Patients undergoing urologic procedures may be at increased risk. It is hypothesized that chlorhexidine uptake into the bloodstream may be efficient through the bladder and urethral mucosa. The vast majority of case reports of chlorhexidine-mediated anaphylaxis attributed the event to the use of chlorhexidine lubricants for urinary catheter insertion and chlorhexidine-coated central venous catheters (CVCs). The third most common method of exposure associated with anaphylaxis was topical application.

**Table 159.2 ■ Common Causes of Intraoperative Allergy**

| | |
|---|---|
| Neuromuscular blockers | 61.9% |
| Antibiotics | 14.5% |
| Latex | 9.2% |
| Chlorhexidine | 5.2% |
| Hypnotics | 2.6% |
| Protamine | 2.6% |

Reprined from Antunes J, Kochuyt AM, Ceuppens JL. Perioperative allergic reactions: Experience in a Flemish referral centre. Allergol Immunopathol (Madr). 2014;42(4):348–354. Copyright © 2013 SEICAP. With permission.

## Diagnosis

Patients with chlorhexidine-induced anaphylaxis commonly present with an erythematous rash or hives, hypotension, and tachycardia. Of note, bronchospasm seems to occur rarely. Anaphylaxis to chlorhexidine-coated CVCs may be difficult to diagnose, particularly if hypotension is the main feature, and may be mistaken for anesthesia-induced vasodilation or a complication from central line placement. Delayed recognition may also complicate resuscitation efforts and contribute to higher clinical severity, prolonged resuscitation, and the need for intensive care admission. In contrast, type IV hypersensitivity has a much milder presentation. Patients classically have prominent cutaneous findings characterized by erythematous patches with vesicles that may rupture or crust.

If a diagnosis of chlorhexidine-induced anaphylaxis is suspected, a serum tryptase level should be sent within 1 to 2 hours of the event, and again at 24 hours to confirm resolution and establish a baseline. The magnitude of tryptase elevation has been shown to correlate with the drop in mean arterial pressure and has a positive predictive value of 93%. Serum-specific IgE to chlorhexidine can also be assayed and has nearly 100% specificity.

## Management

Initial management of anaphylaxis includes removing the precipitating agent, aggressive fluid resuscitation, and treatment with epinephrine. $H_1$ and $H_2$ antagonists, bronchodilators, and steroids may be considered. Following a suspected type I chlorhexidine reaction, the FDA recommends that clinicians use alternative antiseptics such as povidone-iodine, alcohols, benzalkonium chloride, benzethonium chloride, or parachlorometaxylenol. Additionally, the patient should be referred to an allergist for skin prick testing. Consensus guidelines recommend that skin testing occur within 3 to 7 months following reaction. Patients with evidence of delayed hypersensitivity or contact dermatitis to chlorhexidine should undergo skin patch testing with the allergen. Such evaluation is critical as it not only confirms the diagnosis, but also eliminates other agents or drugs as the culprit and can provide recommendations for future anesthetic procedures. (See Table 159.3.)

**Table 159.3 ■ Suggested Management of Intraoperative Anaphylaxis**

1. Remove suspected allergen
2. Call for help
3. Maintain airway, administer 100% oxygen
4. Give IV fluid bolus and position the patient to optimize preload

5. Administer epinephrine: 0.2–0.5 mg IM or increasing doses of 10–100 µg IV
6. Once stabilized, consider diphenhydramine 50–100 mg IV, ranitidine 50 mg IV, bronchodilators, and methylprednisolone 125 mg IV
7. Draw serum tryptase level
8. Refer to an allergist with expertise in drug allergy testing

## TAKE HOME POINTS

- Health care providers should consider chlorhexidine as a potential source of allergy as it is now impregnated on many medical devices.
- Although initial presentation may be mild as contact dermatitis, chlorhexidine allergy carries a risk of life-threatening anaphylaxis.
- Patients with hives, flushing, or hypotension after exposure to chlorhexidine should have serum tryptase levels drawn within 1 hour followed by referral to an allergist for skin prick and patch testing.
- Patients diagnosed with chlorhexidine allergy should be given alert identification.

## Suggested Readings


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# What Is the Correct Brachial Plexus Block to Perform?

Nathalie Lunden, MD and Raymond G. Graber, MD

It is a valuable skill to be able to perform brachial plexus blocks for upper extremity surgery. Wouldn't it be nice to avoid a general anesthetic in the patient with a full stomach? How about providing prolonged pain relief in the opioid-tolerant patient? What about speeding your patients through the recovery room with less pain and nausea to an earlier discharge? Sounds good, right! Well, there are several different approaches to blocking the brachial plexus, and they each have different areas of coverage because of the underlying anatomy, and different potential side effects and complications. Once you understand all of this, you will be better able to match the right block with the right surgery and the right patient.

## Anatomy—The Road Map …

The brachial plexus is typically comprised of five roots, three trunks, six divisions, three cords, and the terminal branches. (Pick your favorite pneumonic: "**R**obert **T**aylor **D**rinks **C**old **B**eer," "**R**ead **T**hat **D**amn **C**adaver **B**ook," and others.) The roots are the anterior divisions of the C5–8 and T1 spinal nerves. These pass out of the intervertebral foramina, between the anterior and middle scalene muscles. These muscles arise off the anterior and posterior tubercles of the cervical transverse processes, and insert onto the first rib. The muscle fascia forms a nice sheath around the plexus and guides it under the clavicle and over the first rib toward the axilla. The subclavian artery also crosses over the first rib on the medial side of the plexus, gets renamed the axillary artery, and travels with the plexus (in the same sheath) to the axilla.

Within the sheath, The C5 and C6 roots unite to form the superior ("upper") trunk of the plexus; the C7 root becomes the middle trunk; and the C8 and T1 roots unite to form the inferior ("lower") trunk. This occurs between the scalene muscles and prior to reaching the first rib. At the lateral border of the first rib, the trunks divide into divisions. Under the clavicle, the divisions rearrange into cords. By the time the plexus reaches the axilla, the terminal branches have formed.

This description is the classic schema, but there is a lot of potential for anatomic variation. For example, sometimes C4 and T2 may also contribute, and sometimes roots may lie within the anterior scalene muscle.

So, what can we do with this information? Since there is this nice sheath that surrounds the plexus, we can enter it at different locations to inject local anesthetic. The resulting block depends on what nerves are within the sheath, what nerves have already exited, and how well the local anesthetic spreads to surround our intended target. The subclavian and axillary arteries are useful landmarks for identifying the plexus.

## Interscalene Block—Taking the High Road …

The interscalene block (ISB) is the most proximal brachial plexus block. Local anesthetic is injected into the sheath between the anterior and middle scalene muscles, classically at C6. The local anesthetic generally spreads to cover C5, C6, and C7 (or the superior and middle trunks), but does not reliably get C8 and T1. As a bonus, local anesthetic also spreads upward to get the lower roots of the cervical plexus (C3, 4)—which are the origins of the supraclavicular nerve. This leads to good coverage of the skin on top of the shoulder (the cervical plexus "cape") in addition to the brachial plexus block. The net result is that the ISB works very well for shoulder, clavicle, and proximal humerus surgery. It will not be a good choice for surgery involving the C8–T1 distribution—medial arm and forearm, and ulnar nerve territories.

When using ultrasound to perform an ISB, we typically look for a "stoplight pattern." What you will see is three hypoechoic circles stacked on top of each other between the muscle bellies of the anterior and middle scalene. These three structures typically represent the C5 and divided C6 nerve roots. To find this stoplight pattern, we typically will place our ultrasound probe above the clavicle, find the subclavian artery and brachial plexus, then trace the plexus up until we get the picture we want.

Now, ISBs do have side effects and complications. Normal side effects (due to spread of local anesthetic to nearby structures) include phrenic nerve block (up to 100%!), hoarseness (<5%), and Horner syndrome (up to 75%). We generally council our patients that they may notice some difficulty when trying to take a deep breath, and that a pupil may be smaller—and these phenomena will go away as the local anesthetic wears off. Complications (due to improper needle placement) include pneumothorax, intravascular injection, long-term nerve injury, and epidural or intrathecal injection. These are rare.

The main drawback to a classic ISB is the potential for phrenic nerve block. You have to decide whether your patient can tolerate an estimated 25% reduction in pulmonary function. If not, then you are best off looking at alternative blocks or modifications in technique.

## Supraclavicular Block—Always Supra, Often Super as Well

The supraclavicular block (SCB) is performed just above the clavicle, targeting the plexus where it and the subclavian artery cross over the first rib. Thus, this technique is a block of the brachial plexus either at the distal trunk or proximal division level. When using ultrasound, you will notice that the nerves of the brachial plexus appear as a mass of hypoechoic circles grouped just anterior and lateral to the subclavian artery (like a "bunch of grapes"). Because of the tight bundling of nerves and the relative ease of identification, this block provides excellent anesthesia of the arm, elbow, forearm, and hand. For this reason, some practitioners have called this block the "spinal of the arm." This block has also been used for shoulder surgery. The caveat is that the cervical plexus skin coverage may not be as reliable as with ISB, and sometimes additional superficial cervical plexus blockade may be required.

The SCB has some of the same side effects and complications as the ISB. Prior to the use of ultrasound, the pneumothorax incidence was as high as 5%, and this scared away many practitioners. With ultrasound, the incidence has dropped close to zero. Phrenic nerve block (up to about 65%), and Horner syndrome can also occur. So, you still have to be careful about using this block in patients with poor respiratory reserve.

## Infraclavicular Block–Emerging From the Tunnel

The infraclavicular block (ICB) is commonly performed medial to the coracoid process and inferior to the clavicle, and is a block of the cords of the brachial plexus. When using ultrasound, the three cords of the brachial plexus are seen to surround the axillary artery. Some early approaches using one site of injection showed sparing of the radial nerve. However, when two or three injections are made and local anesthetic can be seen surrounding all the cords, this problem goes away. Like the SCB, the ICB provides excellent anesthesia of the arm, elbow, forearm, and hand.

One big advantage of the infraclavicular approach is that the rate of phrenic nerve block is near zero. The risk of pneumothorax is also near zero with the coracoid approach and using ultrasound.

## Axillary Block—Taking the Low Road

The axillary block (AXB) is performed in the axilla, and is a block of the terminal branches of the brachial plexus. At this location, the radial, median, and ulnar nerves lie within the brachial plexus sheath around the axillary artery. To be more specific, each of these three nerves lie within a roughly 120-degree sector around the artery—the radial nerve lies posterior to the artery, the median nerve lies anterior-superior, and the

ulnar nerve lies anterior-inferior. Wait, what about the musculocutaneous nerve? Well, typically it has already exited from the sheath and lies within the substance of the coracobrachialis muscle a variable distance away from the rest of the plexus. If you ultrasound scan from proximally to distally, you will see the oval-shaped musculocutaneous nerve "swim" away from the rest of the plexus.

In the preultrasound era, single injection techniques frequently resulted in patchy radial and musculocutaneous blocks. This makes sense anatomically, because the radial nerve hides deep to the artery, and the musculocutaneous nerve is not in the sheath. So, the solution was to inject at least three locations—superficial to artery (to get the median and ulnar nerves), deep to artery (to get the radial nerve), and also into the muscle to get the musculocutaneous nerve. This was done either by using nerve stimulation, or via using the transarterial technique (find the artery on purpose, poke through, inject some local, pull out, and inject more local). In present times, and using ultrasound guidance, we typically do a periarterial technique. You can inject posterior to the artery to get the radial nerve, then anterior to the artery to get median and ulnar nerves. The median and ulnar nerves are frequently visible with ultrasound, while the radial is much harder to visualize. To finish the job, the musculocutaneous nerve can usually be identified, then injected.

Since this is a block of more distal nerves, it is indicated mostly for surgical procedures of the elbow, forearm, and hand.

## Those Darn Unblocked Territories

Even a perfectly placed and effective brachial plexus block will not cover the axilla and proximal medial arm! That isn't your failure, that is anatomy! That territory is innervated by the intercostobrachial nerve, a branch of the second intercostal nerve (T2). There are some occasional shoulder surgery incisions that can wonder down into this area. In addition, this territory may also be compressed when an upper arm tourniquet is in use, with resultant tourniquet pain. The intercostobrachial nerve is generally blocked by injecting a subcutaneous line of local anesthetic in the axillary crease, with the bulk of the local placed over the axillary artery.

As we stated above, the superficial cervical plexus innervates the skin over the top of the shoulder. If your choice of block misses this territory, you can rescue it in one of two ways. You can either do a superficial cervical plexus block along the posterior edge of the sternocleidomastoid muscle, or you can inject a line of local anesthetic subcutaneously above and parallel to the clavicle to just get the supraclavicular nerve branches.

Another location that can be inadequately blocked is the posterior portal used in shoulder arthroscopy. This may fall within intercostal nerve territory rather than the

cervical plexus distribution. We frequently ask our surgeons to inject that site with local anesthetic.

## Putting It All Together …

We have now discussed four different approaches to blocking the brachial plexus. How do you decide what block to do? Well, here are some things to consider…

- ISB is the most reliable block for shoulder surgery.
- Proximal humerus fractures can be done with either ISB or SCB.
- Surgeries of the arm from elbow down can be done with SCB, ICB, or AXB.
- The patient's pre-existing injury may help determine what block you can do. If a patient can't abduct their arm or there is a high cast or splint, it may be difficult to do an AXB.
- In any given patient, different body shapes, pre-existing central lines, scars, etc. may make a particular approach difficult or unsuitable.
- If a patient has significant COPD, sleep apnea, or any other risk for poor respiratory reserve, blocks below the clavicle are preferred to blocks above the clavicle (assuming they provide adequate coverage!)
- We all develop personal preferences for blocks we like to do!

## When Should We Avoid or Delay Doing a Block?

There are certain situations where a block is better avoided or delayed. Some of these will depend on the preferences of the surgeons you work with, and some of these will depend on patient issues…

- There are some surgeries where there are nerves at risk for getting injured. Our surgeons frequently want to check on and document nerve function postoperatively, before we do a block. For example, midshaft humerus fractures have a risk of radial nerve injury. Ulnar nerve transpositions have risk of worsening ulnar nerve palsy. The brachial plexus lies directly underneath a fractured clavicle. Discuss cases like these with your surgeons.
- There are patients with pre-existing phrenic nerve palsy on the side contralateral to your proposed block. Don't do a block above the clavicle and risk having no diaphragms that work!

- Although long-term nerve injury is rare, short-term phenomena like paresthesias and dysesthesias are more common. For example, Borgeat collected data on patients who had either an ISB or catheter. His group found the incidence of paresthesias/dysesthesias to be 14% at 10 days, 7.9% at 1 month, and 3.9% at 3 months. There are some patients who are extremely dependent on their hand function (e.g., the concert pianist, the ophthalmologist), so this information needs to be discussed prior to any block.

## TAKE HOME POINTS

- The ISB provides excellent analgesia of the shoulder and upper arm but may provide an incomplete coverage of C8 and T1 dermatomes. Phrenic nerve block can occur in up to 100% of patients when classic techniques are used.
- The SCB provides reliable anesthesia of the arm, elbow, forearm, and hand. It can be used in shoulder surgery, with the caveat that the superficial cervical plexus may have to be injected separately. Phrenic nerve block is also an issue.
- The ICB has similar coverage to the SCB but with almost zero incidence of phrenic nerve block.
- The AXB can provide excellent anesthesia of the hand, forearm, and elbow, as long as all four major terminal terms are successfully blocked.

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# Getting the Right Ultrasound Image

Ryan Ivie, MD

Textbook images and expert videos of nerve blocks make them look easy, right? Have you been frustrated that your ultrasound image doesn't look like the idealized images you've memorized? With knowledge of some of the ultrasound controls and transducer maneuvers you too can get a great ultrasound image and make it look easy!

## Picking a Transducer

The first step toward getting the right ultrasound image is selecting the best ultrasound transducer for the job. For the vast majority of blocks, this will mean a high-frequency linear array transducer. High frequency corresponds to short wavelengths which results in high resolution. Higher resolution means a greater ability to distinguish two neighboring structures. Thus, with the high-frequency linear array transducer, you are most likely to be able to distinguish nerves from their surrounding vessels, muscles, and fascial planes. **Visualizing nerves, especially the borders of nerves, at the highest resolution possible likely helps to minimize the possibility of intraneural injection.**

Resolution comes at a cost! The price of resolution is depth. High-frequency waves do not penetrate tissue as deeply as low-frequency waves. As a result, the high-frequency linear array transducers will not generate a good image for deep nerve targets. Fortunately, most of the parts of the body where nerve blocks are performed are relatively superficial such that the high-frequency transducers can be used for the majority of nerve blocks. Some specific nerve blocks, however, routinely require the use of a lower-frequency curvilinear transducer in order to see deep enough to visualize the block target. For example, curvilinear transducers are more frequently used for transgluteal and infragluteal approaches to the sciatic nerve, for neuraxial ultrasound, and for paravertebral blocks. For any nerve block site, if the patient is obese and you find yourself looking at the maximum depth of the high-frequency linear transducer, don't forget to try switching to the curvilinear transducer. With the new transducer, you may turn a dark and blurry image into a high-quality picture.

## Ultrasound Controls

Now that you have the right transducer, let's talk about all the buttons on the ultrasound machine. Three of the most important controls that you'll need to know for getting best image are (1) depth, (2) gain, and (3) focal zone.

The **depth** button or knob will control the maximal distance from the skin for which the ultrasound machine will process an image. For deeper block sites (e.g., infraclavicular or adductor canal blocks) or for patients with large amounts of soft tissue (e.g., body builders or obese patients), starting with a high depth setting on your ultrasound machine will be necessary in order to locate target structures. For some blocks, like popliteal sciatic block, starting with a deep view may allow you to visualize landmark structures (i.e., the popliteal artery) that will help you locate the more superficial nerve target. Once you've found your block target site, decrease the depth until you're seeing just your target and nearby structures that you need to avoid, like the pleura during a supraclavicular block.

**Gain** refers to how much the returning ultrasound waves are amplified by the ultrasound machine. This means that the higher the gain, the brighter the image. Because ultrasound waves get attenuated (scattered, absorbed, etc.) the deeper they travel, deep structures send weaker signals back to the ultrasound transducer. The weak returning signals from the deep structures need to be amplified, more so than the shallow structures. In most machines, the gain for deeper structures (aka far-field gain) is set higher than that for more shallow structures (aka near-field gain). This is referred to as time gain compensation. If you are having difficulty seeing the deep structures, confirm that the far-field gain is set higher than the near-field gain. If the setting was correct and everything still looks black in the deep field of view, just turn up the far-field gain until the structures brighten up and become visible. Another problem that arises with gain is that the entire image can be too dark or too bright. Both problems can impair the ability to distinguish between structures. In this case, just adjust all the near and far gain settings simultaneously. In addition to a varying number of knobs for adjusting near- to far-field gain, many machines have a total gain knob for just this very purpose.

**Focal zone** describes the depth at which the ultrasound beams are optimally focused, providing the highest lateral resolution. This means that if your block target is at the same depth as the machine's focal zone you will get the best image! Some machines allow the manual control of the focal zone with a separate dial. Other machines have the focal zone built into the depth setting. With these machines, just make sure to find your target, then decrease the depth setting so only your target structure and its immediate neighbors are visible. Leaving excess depth visualized will place the transducers' focal zone deeper than the site you're trying to block. In some of the newest machines, the focal zone can also be controlled with a feature that encapsulates focal zone along with

other more complex features in a simple button that describes normal versus obese patients. With the click of a button, this user-friendly addition can help optimize the image for deeper structures.

## Transducer Maneuvers

Alright, so now you have the best transducer and you know all the correct buttons to press. Using your knowledge of anatomic landmarks, you scan with the transducer and look for anchoring structures that are easily visualized with ultrasound. Examples of such anchoring landmarks include the subclavian artery for the supraclavicular brachial plexus block or the greater trochanter for the transgluteal sciatic block. Identifying these landmarks first allows you to build a spatial framework from which you can subsequently identify the more subtly visualized nerve or fascial targets. But this anatomic knowledge isn't enough to get the best ultrasound image. There are nuances to the positioning and movement of the ultrasound transducer that are needed to optimize your view.

One of the most important steps in getting the right ultrasound image is understanding that structures are most optimally visualized when the ultrasound is oriented perpendicular to the object of interest. When the ultrasound beams hit the nerve(s) of interest in perpendicular cross section more of the ultrasound waves return to the transducer and the structure is shown as bright and clear as possible. In contrast, when the ultrasound beams hit the nerve at an angle many of the waves get deflected and don't return to the transducer. This means you can't as easily distinguish the nerve from its surrounding structures. **This phenomenon of changing appearance based on the angle at which the ultrasound beam contacts the target is called anisotropy. Two nerve blocks for which anisotropy is frequently relevant are the femoral nerve block and the popliteal sciatic block**. Neither of these nerves are typically traveling parallel to the skin at these locations. As a result, if you place the transducer perfectly perpendicular to the skin you likely won't see the image you had hoped for. But if you tilt the transducer, you'll angle the ultrasound beam and eventually hit the nerve perfectly in cross section. For example, with the popliteal sciatic block, as you tilt the transducer to angle the beam more down toward the foot you'll see the nerve get brighter and brighter. Once you find the tilt that optimizes the nerve image, try to keep that tilt fixed during the nerve block as you move the transducer proximal/distal or medial/lateral.

If you compare novice users of ultrasound to experts, you'll quickly notice a difference. Novice users often hold the transducer relatively static or make staggered movements of the transducer. Experts learn to appreciate the importance of dynamic scanning. This refers to smooth fluid movement of the transducer, typically in a

proximal-distal direction, along the course of the target nerve. Translating the transducer in these flowing motions helps clarify the location and the borders of hard to visualize structures. Structures that appear subtle on a static image (e.g., a branching nerve, an ambiguous edge of a muscle) can become obviously apparent with a dynamic scan. So, don't be afraid to apply some extra ultrasound gel and scan the area all around your block site to help all the relevant structures really pop out at you.

How about those times when you get the right ultrasound image before you insert your needle, but once the needle is in you just can't get a good image of it despite being perfectly lined up? Frustrating! Next time, try rocking the transducer. To rock or "toe-in" the transducer means to press harder with one side of the transducer. With rocking, the transducer footprint isn't evenly applied to the skin. Rather, one end of the transducer footprint is pressed into the skin more deeply while the other end is contacting the skin with minimal pressure. This left or right rocking motion is in the same plane as the field of view, so should not distort your image of the nerve. If you rock in the direction that makes the transducer footprint mirror the needle's angle, the ultrasound beams will be more perpendicular to the needle. As a result, more ultrasound waves will be reflected back to the transducer, and you'll get the needle image you were hoping for!

There are a few other strategies that can also be used to help better visualize the needle. Plan your insertion site to achieve a shallower angle of approach. This means inserting the needle a few centimeters away from the transducer. By avoiding a steep needle trajectory, you keep the needle more parallel to the transducer footprint and keep the ultrasound beams more perpendicular to the needle. Also try using echogenic needles which have little notches allowing better reflection of ultrasound waves back to the transducer. And don't forget about "hydrolocation." This is the injection of a bit of fluid (saline or D5W) to make the needle tip location more apparent. Not only does the fluid appearing on the screen help you identify the location of your tip, surrounding the needle tip with fluid actually helps the ultrasound create a more clear image of the needle!

Sometimes the only thing keeping you from a high-quality image is the amount of pressure you're applying with the transducer. Try increasing the amount of pressure to see if it enhances the nerve image. But don't forget to release this pressure prior to inserting the needle to make sure that you haven't compressed any veins that are in the needle path.

Finally, keep your area of interest in the middle of the screen. Remember the focal zone? This zone of optimal resolution occurs in the middle of the screen. Therefore, the image quality is typically the highest when the target is centered on the ultrasound screen. This simple trick can be just what it takes to turn a dull indistinct nerve border

into a crisp hyperechoic edge.

## TAKE HOME POINTS

- A high-frequency linear array transducer will get you the best, most detailed image of your target structures for the majority of blocks and patients.
- Start with a deep field of view while you hunt for your target structures, then shallow the view once you find your target.
- Make sure that the far-field gain is higher than the near-field gain to compensate for the attenuation of ultrasound waves, helping to brighten up the deeper structures.
- Tilt the ultrasound transducer so its waves cross the nerve(s) in perpendicular cross section to make nerves the brightest.
- Dynamically scan proximal-distal and/or medial-lateral with fluid motion to help distinguish subtle structures.
- When your needle is steep and you can't get the right image, rock the transducer by pressing one end deeper than the other to bring it more parallel to the needle.

With these tips your ultrasound images will start to look less like static on an old TV and more like a beautiful sonographic representation of human anatomy!

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# Interscalene Blocks—Preventing the Blues!

Raymond G. Graber, MD and Lindsay Wetzel, MD

A 50-year-old man presents for arthroscopic repair of the left rotator cuff. He is 6'3" and weighs 380 lb. He is a smoker for over 20 years. He is under treatment for hypertension, hyperlipidemia, and gout. He carries no formal diagnosis of sleep apnea, but his wife says he is a heavy snorer. Is an interscalene block a good choice of analgesia for this patient? What are the potential respiratory effects of interscalene blocks?

Interscalene blocks are a popular form of analgesia for shoulder surgery. Why is this? The two fold answer is that this block is relatively easy to do, and it generally works very well. **The skin innervation of the shoulder is split between the cervical plexus coverage of the top of the shoulder (the "cervical plexus cape") and brachial plexus coverage of the skin of the upper arm.** The brachial plexus is responsible for all the innervation of the bony elements of the shoulder, and all the muscles, too. The cervical plexus is formed from the roots of C1 to C4, while the brachial plexus is formed from the roots of C5 to T1 (anatomic variations exist). These roots get enclosed in a fascial sheath between the anterior and middle scalene muscles, and this sheath extends from the transverse processes down into the axilla. So when a classic interscalene block is performed at C5–6, local anesthetic spreads upward to get the cervical plexus, and downward to get the brachial plexus. The result: excellent analgesia, less narcotic requirements, less nausea, shorter recovery room stays, and fewer hospital admits for pain or nausea control. Patients, surgeons, and administrators are happy!

## Complications

Now, interscalene blocks do have side effects and complications. Normal side effects (due to spread of local anesthetic to nearby structures) include phrenic nerve block, hoarseness (<5%), and Horner's syndrome (up to 75%). Complications (due to improper needle placement) include pneumothorax, intravascular injection, nerve

injury, and epidural or intrathecal injection. Let us focus on the issues that can lead to breathing problems—phrenic nerve block, pneumothorax, and epidural or intrathecal injections.

**Now you might think that pneumothorax risk is a big deal, but it is not, as long as you are careful**. In olden times, when we did these blocks at C6, by palpating muscle grooves and using nerve stimulation (and "gasp," no ultrasound!), we were far away from the lung apex that rises into the neck. Supraclavicular blocks were another story, as pneumothorax rates of 1% to 5% were seen. Nowadays, almost everyone uses ultrasound, and although it is great to be able to see muscle bellies and nerve structures, we frequently do blocks further down the neck, and closer to the lung. So, make sure that the further down the neck you go, the more compulsive you are about visualizing your needle. There are a few case reports of pneumothorax secondary to ultrasound guided interscalene block—but the incidence is small—1/509 in one series (Marhofer), and none in other registries.

What about intrathecal injections? Intrathecal injections are extremely rare—and these were reported back in the pre-US era when physicians were probing blindly and deeply with needles searching for a paresthesia or a twitch with a nerve stimulator. With ultrasound techniques, you should never be near the cerebrospinal fluid. However, there are a few case reports of interscalene catheters that wound up being thread across the dura. (That's a bad day!)

What about epidural spread? Well, this is an interesting story. You would think that it would be difficult to get an epidural position for your block needle, and you would be right. But guess what—at our institution we have seen two epidural "injections" (over about 25 years). In these cases, the arm being blocked went numb first, followed by the patient noting that the other arm was going numb. The patients soon became dyspneic, but on the other hand were hemodynamically stable. The patients were induced, intubated, and the cases proceeded. At the end of surgery, the patients were extubated, with apparent recovery from the epidural spread, and with intact block on the operative side. A group from Austria had a similar experience, and so did a cadaver study to investigate. They used ultrasound to inject contrast dye at the C5–6 location in the brachial plexus sheath. They injected in increments, and then did CT scans after each injection. They saw spread of dye to the ipsilateral epidural space in 4 out of 5 cadavers, and spread to the contralateral side in 2 of them! They then went on to repeat this in live patients, and did MRI imaging. They injected either 5 mL or 20 mL of local anesthetic/dye mix. And guess what—they saw spread into the ipsilateral epidural space in 13% of patients in each group. So, what we now know is that local anesthetic, when it is injected, will travel not only within the brachial plexus sheath, but also back along the nerve roots to the paravertebral space, and into the epidural space in some

patients. This appears to be clinically insignificant. In rare instances, it can spread to the other side, and then it is a problem.

## Phrenic Nerve Block

OK, now we get to the main issue, and that is phrenic nerve block. In 1991, we learned that 40 mL of local anesthetic injected at the C6 interscalene block location resulted in 100% incidence of ipsilateral hemidiaphragmatic paresis. This was presumed to be secondary to phrenic nerve block. The result was about a 25% decrement in vital capacity, peak flows, FEV1, and so forth. So, maybe that is why all my old chronic lung patients were turning blue after interscalene block!

Why does phrenic nerve block occur? There are two possibilities. Local anesthetic can spread up the brachial plexus sheath to the roots that form the phrenic nerve (C3–C5). Alternatively, local anesthetic can spread from the point of injection, and spread to directly contact the phrenic nerve. The phrenic nerve lies on top of the anterior scalene muscle, and at the C6 level, may only be a few centimeters away from the brachial plexus.

How is phrenic nerve block diagnosed? It is typically diagnosed by using ultrasound to observe how a diaphragm moves. (Fluoroscopy has also been used.) Normally, a diaphragm will descend with inspiration. When paralyzed, it will ascend instead. This is because the accessory muscles of respiration are causing rib cage expansion, and the diaphragm passively goes along for the ride.

What is the clinical significance? The phrenic nerve block will wear off as the local anesthetic wears off. Most healthy patients will tolerate the 25% drop in pulmonary function without a problem as long as they are at rest. (Do not ask them to go run laps, however!). Patients with severe COPD, or other conditions with minimal respiratory reserve, can develop dyspnea and hypoxia.

**When a patient complains of dyspnea, how is this managed?** First of all, we always elevate the back of the bed—the more upright the patient is, the easier it is for them to breath. Next, supplemental oxygen is administered and titrated to a reasonable saturation level. Most patients will then require time for the block to wear off. (The outpatient surgery has just become a 23-hour stay.) On occasion, a patient will required assisted ventilation with noninvasive or invasive techniques.

So now we have this quandary—if we have a patient who presents for shoulder surgery with bad lungs or sleep apnea, is it better to give them narcotics (and risk all the narcotic side effects), or do a block (and knock out about 25% of their lung function!)?

Researchers have attempted to come to our rescue, by investigating strategies to reduce the risk of phrenic nerve block:

- Is there a volume effect? Would reducing volume reduce the spread of local anesthetic

to either the roots of the phrenic nerve or the phrenic nerve itself? The answer is yes. If you do an ISB at C5–6 with 0.5% ropivacaine, injecting volumes of 10, 20, or 40 mL will all produce a phrenic nerve block rate of 90% to 100%. Dropping to 5 mL reduces the rate to about 50%.

- Is there a concentration effect? Would a lower local anesthetic concentration have less motor block? The answer is yes. For example, if you do an ISB at C5–6 with 10 mL of local anesthetic, and reduce the concentration from 0.5% to 0.25%, the phrenic nerve block rate drops from 80% to 20%.

- Is there a location effect? Would injecting at a lower level (further away from either the roots of the phrenic nerve or the phrenic nerve itself) reduce the incidence of phrenic nerve block? The answer is yes. For example, if you inject 5 mL of 0.5% bupivacaine at the superior trunk or 4 cc 0.75% ropivacaine at C7, investigators have reported no phrenic nerve block.

So, reducing volume and placing it lower in the neck seems to be a promising strategy to reduce the incidence of phrenic nerve block. One caveat here is that this tactic may result in inadequate spread to the cervical plexus—and thus potentially inadequate skin coverage. The solution to this issue is to have your surgeon infiltrate all incisions and portals with local anesthetic. In the recovery room, if the patient is having what appears to be incisional pain in the cervical plexus territory, we have done a superficial cervical plexus field block as a rescue technique. Instead of infiltrating along the border of the sternocleidomastoid muscle, inject a subcutaneous line of local anesthetic above and parallel to the clavicle, starting laterally and finishing at the approximate location of the middle scalene. Using this technique, you get just the branches that go toward the skin of the shoulder, and stay away from accidentally getting the phrenic nerve.

In addition to the above strategies, remember to use multimodal analgesia. Many blocks are analgesic, but not anesthetic. We typically administer oral acetaminophen and IV ketorolac to all patients (unless contraindicated by allergy, renal function, etc.). Also, do not forget that icing up can be helpful, so ask the nurses to place bags of ice on the affected shoulder in the recovery room.

One more strategy under investigation is to do blocks even more distally—on individual peripheral nerves such as the suprascapular and axillary nerves. Injecting at these locations guarantees no phrenic nerve block, but the immediate postop analgesia is not as good. Promising, but the jury is still out.

Getting back to the patient described at the beginning of the chapter, you will recall that we had a smoking, obese, snorer of a patient. Do you have cause to be concerned? Sure you do—he's at high risk for oxygen desaturation in the recovery room if you

knock out his diaphragm. On the other hand, narcotics could precipitate obstruction and sleep apnea symptoms. **So what did we do?** We did a trunk level block with about 10 mL of 0.25% bupivacaine. We had the surgeon infiltrate the skin incision and portal sites. In the recovery room, he got 975 mg oral acetaminophen, 30 mg IV ketorolac, and 5 mg oxycodone and an ice bag. He went home with a mildly achy shoulder, breathing deeply, a smile on his face, and he was not blue at all.

## TAKE HOME POINTS

- Interscalene block provides effective analgesia for shoulder surgery.
- Classic interscalene technique performed at C5–6 with high volumes of local anesthetic results in a nearly 100% incidence of phrenic nerve dysfunction.
- There are other much more rare reasons for respiratory dysfunction—including pneumothorax, intrathecal injection, and epidural spread.
- Classic interscalene technique can be modified to reduce the risk of phrenic nerve dysfunction (low volumes, placed at C7 or trunk level).
- An alternative analgesic strategy would be to block some of the more distal peripheral nerves that innervate the shoulder such as the suprascapular and axillary nerves. These offer the advantage of no phrenic nerve block, but the analgesic effectiveness is not as good.
- Supplement your blocks with multimodal analgesia and surgeon-injected local anesthetic.

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# The Old-Fashioned "Bier" Block Is Still Relevant—The Trick Is to Not Let the Surgeons Get Ahead of You

Raymond G. Graber, MD, Michael Barts, CRNA APRN BS Anesthesiology, and Surjya Sen, MD

A 26-year-old woman with no significant past medical history presents for removal of a ganglion cyst on the dorsum of her wrist. The surgeon predicts a quick procedure, and an intravenous regional anesthetic with lidocaine is chosen. As promised, from incision to closure, the operation is completed within 12 minutes. Planning for a rapid turnover and quick recovery, the tourniquet is released and the patient is taken to the postanesthesia recovery unit. Within seconds after arriving, the patient begins to complain of severe pain at her incision site, then dizziness, and, ultimately, she begins to seize. What happened? Could such an outcome have been predicted? If so, what could have been done to prevent it?

## Introduction and History

Described by August Bier in 1908, "vein anesthesia" was originally proposed for surgery of the elbow and amputations of the feet. It was noted to use a "new avenue" for getting the anesthetic agent "to the end apparatus of the nerves as well to the nerve trunks": the blood vessel. Though Bier reported his method in at least five journals over the course of 2 years, the technique did not rapidly gain popularity. It involved special equipment (Esmarch bandages were not widely available at the time), meticulous exsanguinations of the limb, and a cutdown to locate the vein. With the introduction of brachial plexus blocks in 1911, interest in "vein anesthesia" quickly faded.

Nearly three decades after its introduction, use of the technique surged when it became particularly useful on the battlefields of World War II. The introduction of safer amide local anesthetics (i.e., lidocaine), the use of percutaneous needles to cannulate veins, and the introduction of a commercially available double-cuff tourniquet helped what was then known as the Bier block gain popularity.

## Advantages and Disadvantages

With some of the initial disadvantages being overcome by advancements in the field of anesthesia, the advantages of the block are more apparent. From a technical standpoint, all that is needed is successful cannulation of a vein in the involved extremity. Anesthesia can be set up quickly and easily, the length of anesthesia is predictable, recovery is rapid, and the block itself is extremely reliable.

Any clinician planning to use the block technique must also be aware of the disadvantages of the procedure. As originally described by Bier himself, upon release of the tourniquet, the local anesthetic may cause systemic toxicity. Second, pain from tourniquet use is the primary limitation on the duration of anesthesia. To combat this, double tourniquets and subcutaneous infiltration anesthesia have been proposed but have not yet eliminated this limitation. It is also important to note that postoperative pain relief is virtually nonexistent with this method. Unlike brachial and lumbar plexus blocks, once the tourniquet is released, surgical anesthesia quickly dissipates and the patient is left without the benefit of residual analgesia.

Two other limitations involve patient selection. First, the block cannot be used for a patient in whom movement of the operative extremity causes pain. The process of exsanguination with an Esmarch bandage can generate significant pressures that can be quite painful. Second, the venous system of the involved extremity must be intact. Traumatic hematomas, open fractures, and the like are contraindications to performing the block.

## Technique

) Place a small-gauge intravenous catheter in the distal portion of the extremity to be blocked. A smaller gauge helps decrease the area through which the injected local anesthetic can ooze out after exsanguination and tourniquet inflation.

) Wrap soft cloth over the proximal portion of the extremity to be blocked. This wrap should be free of wrinkles and have a smooth circumferential fit, since the tourniquet will compress it.

) Place the tourniquet over the cloth padding. Raise the limb to allow venous drainage via gravity. To exsanguinate the forearm and particularly the hand for the purpose of finger, hand, or wrist short procedures, one of the authors (M.W.B) has the patient squeeze a tennis ball in his hand. The ball has the correct shape, size, and degree of hardness to force the palmar blood out during Esmarch exsanguination. The structures of the hand remain in an anatomic alignment, so there is less discomfort with compression. If cross contamination of the ball is a concern, first place the ball in a disposable glove for protection.

) Next, exsanguinate the extremity by wrapping an Esmarch bandage in a distal to

proximal manner.

) Inflate the tourniquet to 300 mm Hg. If using a double tourniquet, inflate the distal cuff first. Then, inflate the proximal cuff and deflate the distal cuff.

) Inject local anesthetic into the vein, and raise the extremity to allow "downward" flow via gravity.

') The block is significantly better tolerated with concomitant intravenous sedation (via an intravenous catheter in the other arm, of course!). Sedation can specifically help a patient tolerate pain from tourniquet use for longer durations and may raise the patient's seizure threshold. If a double tourniquet is used, inflation of the distal cuff followed by deflation of the painful proximal cuff can add 15 to 30 minutes of operative time. Alerting the surgeon of this "window" of time when the cuff is changed is important.

## Agents and Adjuncts

In the United States, the local anesthetic agent of choice is lidocaine. Large volume, dilute concentrations (i.e., 50 mL of 0.5% lidocaine) have been advocated, but smaller, more concentrated amounts (12 to 15 mL of 2% lidocaine) can also serve the same purpose. Mepivacaine provides a well-tolerated alternative to lidocaine, one that has some longer anesthetic and analgesic effects after the tourniquet is released. However, there is some controversy about its use, because it tends to be vasoconstrictive and thus may not be appropriate for use in all patients. In parts of Europe, prilocaine is extensively used for intravenous regional anesthesia. It is favored because of its extremely low risk of systemic local anesthetic toxicity. However, because of the risk of methemoglobinemia, it is not available for this use in the United States. Although ropivacaine, bupivacaine and, levobupivacaine have been described and investigated for use in the Bier block, these pose much higher risk of cardiac toxicity, and should not be used in this technique.

Various adjuncts to the use of local anesthetics have also been studied. In general, these adjuncts have been investigated to see if they would speed onset of block, reduce tourniquet pain, or provide postop analgesia. Drugs such as ketorolac, ketamine, clonidine, magnesium sulfate, and dexmedetomidine have been studied, with varying success and potential side effects. Some of the analgesic benefits seen may actually be due to systemic effects of the additive rather than due to local effects at the tissue level. At this time, no specific additive is recommended for routine use.

## Cautions

The most common complication of the use of intravenous regional anesthesia is that of systemic toxicity of local anesthetic. The clinician should be aware of both central

nervous system and cardiac symptoms of toxicity—especially premonitory ones, such as circumoral numbness, dizziness, and tinnitus. To reduce the risk of this complication, most texts recommend that tourniquets be left inflated for a minimum of 20 to 30 minutes, even for procedures that are shorter in duration. Then, the tourniquet should be deflated and immediately reinflated. This can be repeated one to two more times, looking for signs of local anesthetic toxicity after each release. This process allows for a slower release of local anesthetic into the circulation.

Other complications include hematomas (especially at the site of intravenous catheter insertion), ecchymoses, and subcutaneous hemorrhage—all of which require vigilance and careful padding with prolonged direct pressure for treatment.

Lastly, insufficient tourniquet pressure can be of significant concern with this method of regional anesthesia. If the tourniquet pressure is not carefully maintained above systolic pressure, arterial inflow with lack of venous outflow can cause engorgement of the extremity. This can be particularly common with lower-extremity procedures in which arteries can be harder to compress (either due to calcifications or location deep within the leg musculature).

## Getting Back to Our Case …

The patient complained of incisional pain soon after arriving in the PACU. This could have been reduced by good local anesthetic infiltration by the surgeon at the operative site. (Don't ever hesitate to remind them—sometimes they forget!) The patient then noted dizziness, which was followed by seizures. So what we are dealing with now is Local Anesthetic Systemic Toxicity (LAST). This was predictable, because of the short tourniquet time, and the one-time release of tourniquet. The risk of this could have been reduced by keeping the tourniquet up longer, and/or cycling it up and down several times to slow the release of local anesthetic into the circulation. Please refer to Chapter 166 for discussion of the treatment of LAST.

### TAKE HOME POINTS

- Wrap the extremity in soft cloth before placing the tourniquet.
- Use a small intravenous catheter for introducing the local anesthetic.
- Keep an eye on the pressure gauge of the pneumatic tourniquet (or use a constant-pressure automated tourniquet).
- When deflating the proximal cuff and inflating the distal cuff, double check the valves and lines of each cuff to make sure that the proper one is being deflated or inflated. An error in this part of the procedure can introduce a bolus of the local anesthetic into the patient's system with potential risk for toxicity.

- Have a plan for postoperative pain control in place before terminating the block. Peri-incisional infiltration, intravenous opiates, and appropriate amounts of anxiolytics and amnestics can be very useful adjuncts.
- Pay attention to post-procedure tourniquet deflation. If the operation is completed quickly (i.e., in less than 45 minutes when lidocaine is used), multistage deflation to allow gradual washout of the local anesthetic is recommended.

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# Remember the Low-Risk/High-Yield Blocks

Raymond G. Graber, MD and Jennifer Vookles, MD MA

You are in the midst of a busy day in the ortho ORs. You dash through the PACU and happen to notice a patient reading the paper. The next day, you notice another patient in the PACU reading the paper. The PACU nurse tells you that Dr. Doe's patients are so comfortable, they usually ask to read or watch TV while waiting for their floor beds. The following day, when you take your total knee arthroplasty patient to the PACU, the nurse asks if you did a femoral nerve block. When you reply that there wasn't time, she frowns a little and says, "Well, I guess we won't be needing any newspapers today."

Peripheral nerve blocks provide a variety of perioperative benefits. The most obvious benefit is analgesia extending for many hours postoperatively—not only from direct action of the local anesthetic but also potentially from pre-emptive analgesic mechanisms if the block is established prior to incision. In addition, they can help reduce the needed intraoperative doses of volatile agents and opioids; this may reduce recovery times by decreasing postoperative sedation and nausea. Finally, peripheral nerve blocks can also reduce the need for muscle relaxants by blocking motor as well as sensory fibers.

Despite these benefits, peripheral nerve blocks are often omitted when a general anesthetic or spinal are planned because they can be time consuming to perform and carry their own procedural risks. However, even recognizing these limitations, there are a few "low-risk/high-yield" blocks that are relatively quick to perform and should always be considered as an adjunct to one's primary anesthetic. These include the superficial cervical plexus block, femoral nerve block, popliteal fossa block, and ankle block.

## Superficial Cervical Plexus Block

The cervical plexus has both superficial and deep components. The superficial plexus contains cutaneous branches from the ventral rami of C2–4 providing innervation from the posterior cranium to the shoulder via the lesser occipital, greater auricular,

transverse cervical, and supraclavicular nerves. The superficial plexus can be very easily blocked and utilized as supplementary analgesia for carotid endarterectomy (CEA) and other neck surgeries. As the sole anesthetic, one study even found equivalent benefits of the superficial cervical block compared to combined superficial and deep cervical plexus blocks for CEA. It can also be used to ensure cutaneous coverage of the shoulder following interscalene block.

Infiltration of local anesthetic deep to the posterior border of the sternocleidomastoid muscle will block the superficial cervical plexus. At the midpoint of the muscle's posterior border, a 22G 4-cm needle is inserted just deep into the muscle and 5 mL of local anesthetic injected. The needle is then redirected cephalad and caudad along the muscle border with a total of 10 mL injected along these paths. The external jugular vein often overlies this area and should be avoided. When this block is properly performed, deeper structures should not be affected; however, one should be aware of the proximity of the phrenic nerve, internal jugular vein, and carotid artery if the needle is inserted too deeply.

## Femoral Nerve Block

The femoral nerve is formed from branches of L2–L4; it crosses the pelvis in a groove between the psoas and iliacus muscles to emerge beneath the inguinal ligament lateral to the femoral artery. The femoral nerve can begin to divide into its branches at or above the inguinal ligament. This nerve provides both deep and superficial innervation of the anterior thigh extending to the knee with a distal branch, the saphenous nerve, continuing along the anteromedial shin to the ankle and occasionally into the dorsum of the foot.

A femoral nerve block on its own can provide significant postoperative analgesia for surgery involving the anterior thigh, femur, and knee. Common indications include total knee arthroplasty and ACL repairs. The patient may still have some discomfort in the posterior knee, but this is usually easily managed.

Landmarks for the femoral nerve block are the pubic tubercle and anterior superior iliac spine. A line is drawn connecting these points and the femoral artery is palpated along this line. The needle insertion site is on this line immediately lateral to the femoral artery. Using a nerve stimulation technique, injection site can be determined by observing quadriceps twitch; do not be misled by stimulation of the sartorius muscle. Alternatively, ultrasound can be used to visualize the femoral artery, and the femoral nerve located 1 to 2 cm laterally. One thing to keep in mind is that the femoral nerve will split into multiple branches, so in order to see it well you will have to have your ultrasound probe high up in the inguinal crease. A helpful landmark is the branching of the profunda femoris from the main trunk of the femoral artery. Typically the femoral nerve can be visualized as one trunk proximal to that level.

A variant of the femoral nerve block that has recently become popular is the adductor canal block. By performing the block at this location, it is possible to still get good analgesia, but with much less quadriceps muscle weakness. This allows earlier and better participation in physical therapy, so this block is becoming popular for use in patients who have undergone total knee arthroplasty. Ultrasound is used to visualize the femoral artery as it travels underneath the sartorius muscle in the thigh. Many sources recommend a midthigh location, but a more proximal approach also works well. An 80-mm needle is directed (with ultrasound guidance) through the sartorius muscle just lateral to the femoral artery. A local anesthetic (20 to 30 mL) is injected to fill up this compartment.

## Popliteal Fossa Nerve Block

The sciatic nerve is formed from the L4 to S3 segments of the sacral plexus. It travels down the leg in the posterior thigh, and near the top of the popliteal fossa divides into tibial and common peroneal branches. A block performed at this location will provide excellent anesthesia/analgesia of the foot and ankle, except for the medial aspect (which is innervated by the saphenous nerve). It is an excellent block to perform for ankle fracture surgery (but remember you may need to combine it with a saphenous nerve or adductor canal block if there is surgery on the medial aspect of the ankle).

This block can be performed with landmarks and a nerve stimulator, but is much easier when performed with ultrasound. **It can also be performed in multiple positions—and the position you choose may depend on patient body habitus, what is comfortable for the patient, and what works for you.** For example, you can perform it with the patient supine, with the leg up on a support (so that the ultrasound probe can be placed underneath against the popliteal fossa), and the needle is directed from the lateral aspect of the thigh. You can also turn the patient prone or lateral to get access to the popliteal fossa. One of the authors (RG) prefers the prone approach when possible, because ultrasound is easiest to use in that position, and it is also a relatively shallow distance to the nerves.

To identify structures, start your ultrasound scan near the popliteal crease. The tibial nerve can usually be identified lying posterior to the popliteal vessels, within the compartment formed from the muscles of the biceps femoris (laterally) and semimembranosus (medially). As you scan proximally, the common peroneal nerve will emerge from its position adjacent to the biceps femoris, and join the tibial nerve to form the main sciatic nerve trunk. Local anesthetic can either be deposited around the combined trunk or around each branch separately.

## Ankle Block

There are five nerves which innervate the foot: posterior tibial, deep peroneal, superficial peroneal, saphenous, and sural. **The saphenous nerve is the terminal sensory branch of the femoral nerve. The other nerves are all offshoots of the sciatic nerve.** There are two deep nerves: posterior tibial and deep peroneal. The remaining nerves are superficial. These nerves are all blocked separately at the foot or ankle level to provide analgesia of the foot or toes. It is frequently used to provide anesthesia or analgesia for transmetatarsal amputations/debridements and for orthopedic/podiatric foot or toe surgery. This is a particularly easy and safe block to do. Anesthesia providers should be able to readily do it; however, we have noticed that frequently they do not do them or do not do them well. We recommend that you take every opportunity to watch and learn from the podiatrists if you find that your ankle blocks aren't as sure a thing as they might be.

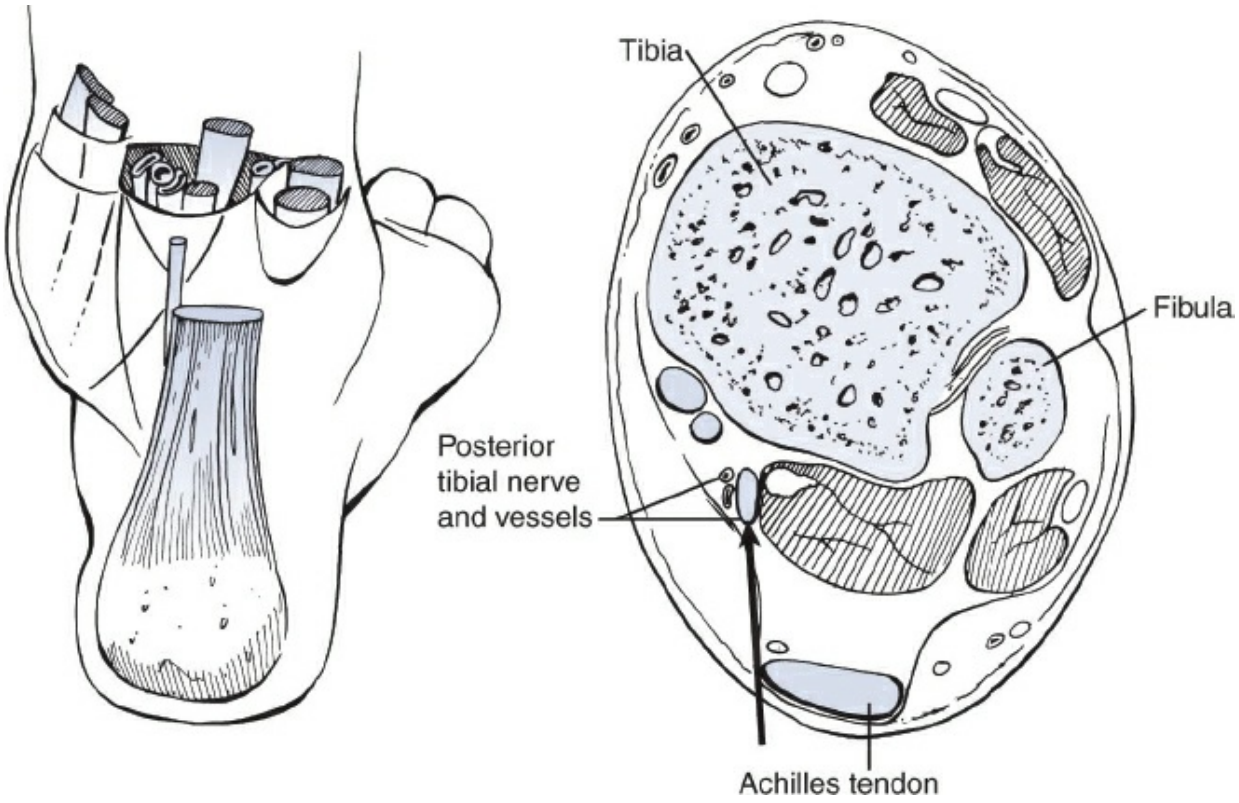


**Figure 164.1.** Surgical anatomy for the ankle block technique. (Reproduced with permission from Thordarson DB. Foot and Ankle. Philadelphia, PA: Wolters Kluwer/Lippincott Williams & Wilkins; 2013.)

To perform an ankle block (Figure 164.1):

- Deep peroneal nerve: The site of insertion is at the top of the malleoli, between the tendons of the extensor hallucis longus and anterior tibial muscles. A needle is inserted perpendicular to all planes, down to bone. The needle is pulled back 1 to 2 mm, then 5 mL of local is injected.

- Saphenous nerve: The site of insertion is midline at the top of the malleoli. The needle is inserted subcutaneously medially toward the medial malleolus. Local anesthetic (5 mL) is injected.
- Superficial peroneal nerve: The site of insertion is midline at the top of the malleoli. The needle is inserted subcutaneously laterally, toward the lateral malleolus. Local anesthetic (5 mL) is injected.
- Sural nerve: A subcutaneous infiltration of 5 mL local anesthetic is made between lateral malleolus and Achilles tendon.
- Posterior tibial nerve: The needle is inserted behind the medial malleolus, posterior to the arterial pulsations of the posterior tibial artery (approximately 1 fb posterior to the malleolus). The needle is advanced until contact with the bone is felt, then pulled back 1 to 2 mm, and 5 cc of local anesthetic is injected.

## TAKE HOME POINTS

- These three blocks can be performed relatively quickly and have relatively low risk associated with them.
- As with any peripheral nerve blocks, care should be taken to avoid local anesthetic toxicity. Always inject slowly and incrementally, attempting to aspirate after every 3 to 5 mL to detect intravascular needle placement.
- Consider adding low-dose epinephrine to the local anesthetic to further aid detection of intravascular injection and slow absorption.
- More precise descriptions of anatomy, innervations, and the techniques for performing these blocks can be found in many regional anesthesia texts or online resources.

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# Preparing to Fail: The Dynamics of a Failed Block

Joelle Karlik, MD and Andrew Neice, MD

A common and frustrating "complication" with peripheral nerve blocks is failed blocks or incomplete blocks. Reasons may include incorrect block for the surgery, incorrect placement, incorrect dosage, varying patient anatomy, and sometimes a bit of bad luck.

Overall, incomplete blocks are much more common than complete block failure. Small studies suggest that use of ultrasound can decrease the incidence of peripheral nerve block failure, whether by single injection or catheter.

## Know Your Anatomy!

The first step for a successful block is ensuring that you are performing the correct block for the surgery and that you, the patient, and the surgeon are aware of potential limitations of the block beforehand. For example, a supraclavicular block for upper arm surgery will not cover the intercostobrachial nerve, and this nerve needs a separate block or a field block performed by the surgeon. Another common example is encountered during arthroscopic shoulder surgery when the posterior arthroscopic port is placed outside of the area covered by an interscalene block.

While these situations are not block failures per se, they will be perceived as such by the surgeon and patient if not addressed proactively. If there is expected residual sensation in an area, then inform the surgeon and patient ahead of time, and develop a contingency plan should the patient tolerate the procedure poorly.

## What If It Just Doesn't Work?

Even in the most skilled hands, some blocks fail. Therefore, even before you place your block, you should have a "Plan B" in mind. "Plan B" may include block supplementation, repeat block, local anesthetic placed by the surgeon, increasing sedation, conversion to general, etc. While block failure is relatively rare, it is important to consent patients in advance for your contingency plan. Your treatment plan will vary depending on where the block fails and the severity of failure.

If you experience incomplete block spread or inadequate block density, then ensure that you've given the block an appropriate amount of time to set up. The amount of time primarily depends on the type of local anesthetic and block site but unknown patient factors may also affect time to complete blockade. Supraclavicular blocks with mepivacaine should set up in around 5 minutes, while a sciatic block with bupivacaine may take 30 minutes to set up fully.

## Blocks for Postoperative Analgesia

If the block was placed for postoperative analgesia and is not your primary anesthetic (e.g., a shoulder surgery under GA with an interscalene block, or a total knee arthroplasty under spinal with an adductor canal block), then there are several possible approaches. Depending on logistics, patient preferences, and total dose of local anesthetic received, the block can either be repeated preoperatively, the block can be abandoned, or the block can be repeated postoperatively. In the latter case, it is important to evaluate the patient's pain control before placing the block. Some patients can do relatively well without a block, and a repeat block may not be indicated.

## Surgical Blocks

If the block is to be used as the primary anesthetic, then block failure is a much bigger problem. A block must not only have appropriate spread but also must be relatively dense to work for surgical anesthesia. We advocate aggressively testing the block before positioning and draping, particularly if the patient is going to have the bed turned, is not supine, or is likely to have a difficult airway. If the block covers appropriate anatomy but may be lacking adequate density, using a nerve stimulator on the blocked area will generally indicate whether the block is dense enough. Many patients will still perceive sensations of touch or pressure with a working block. Some anxious patients will be unable to tolerate these expected sensations and will act much like "block failure." In these cases, sedation with midazolam or propofol will often "salvage" the block.

If block failure is discovered before the start of surgery, the patient can simply be given general anesthesia. If general anesthesia is relatively contraindicated due to patient comorbidities, then the block can be repeated with a decreased dose of local anesthetic.

The most difficult scenario is when block failure becomes apparent intraoperatively. Most common reasons include an inadequately dense block that was not recognized or a block beginning to wear off. In these cases, we have observed that **carefully** titrating sedation can often avoid the need to convert to GA.

In cases where the patient has diminished sensation but is experiencing discomfort,

adding analgesics is often necessary. Fentanyl is most commonly used, but we have noted that alpha-2 agonists (such as dexmedetomidine) or NMDA antagonists (such as ketamine or nitrous oxide) are often highly effective and minimize potential apnea or hypopnea. Of course, this approach may fail and it may still be necessary to convert to general anesthesia or to repeat the block. That may involve taking down the drapes, reprepping and draping, etc. and so we generally advise communicating your intentions and subsequent backup plans with the surgeons early and often.

## Know Your Dosing

When doing salvage blocks, consider the maximum dosing recommendations for local anesthetics. Subcutaneous deposition of excessive local anesthetic can cause delayed local anesthetic systemic toxicity (LAST). Adding epinephrine to your blocks increases your maximum total dosage but avoid it on the fingers, nose, penis, and toes. Fortunately, most salvage blocks are performed on peripheral nerves that are blocked with lower dosages. It is also important to keep in mind that the patient may have received additional local anesthetic from the surgeon, or intravenously to minimize pain from propofol injection, or from a laryngotracheal topical anesthesia (LTA) device.

**We tend to use 1.5% to 2% mepivacaine for preoperative or intraoperative salvage blocks due to its quick onset time.** Other options include lidocaine with or without bicarbonate. Remember: do not combine bupivacaine with bicarbonate unless you want precipitate! Postoperative salvage blocks can provide the patient with hours of pain relief, and therefore we use long-acting agents such as ropivacaine or bupivacaine. At present, we have not found the data on liposomal bupivacaine to be terribly compelling when compared to plain bupivacaine, particularly considering the added expense.

## A Note on Catheters

We prefer to place catheters under ultrasound guidance and deliver our bolus injection through the catheter; this technique ensures that the catheter is in adequate position for postoperative pain control. If a dense surgical block is essential due to severe patient comorbidities, then we may deliver the initial injection through a block needle and place catheter afterward.

### TAKE HOME POINTS

- Incomplete blocks are much more common than true block failure. Have a backup plan ready. Move to the backup plan smoothly and confidently. Never, ever tell a patient to “hang on.”

- An adequate consent process can avoid having a traumatized and angry patient. Always discuss the possibility of block failure and conversion to general anesthesia. A good way to do this is not to portray regional anesthesia and intravenous anesthesia as an either/or thing. And in fact, they are not, as some form of IV agent is almost always given in with regional blocks. In simple terms, you can tell the patient that the anesthetic that is planned for them has both regional block and IV medication components, you will be constantly monitoring their overall anesthetic and analgesic levels and the ratios can easily be adjusted during the case if necessary.
- In the setting of block failure, treat the patient first! Once analgesia and sedation are appropriate, then discuss other options.
- When supplementing blocks, keep total dosage of local anesthetic under maximum limits. Most salvage blocks require decreased dosage.

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# Salvage Techniques for Incomplete Upper-Extremity Blocks

Joelle Karlik, MD and Andrew Neice, MD

You have a 64-year-old man with a history of neck radiation and heart failure presenting for ulnar fracture reduction. To avoid general anesthesia, you place a supraclavicular nerve block under ultrasound guidance. The block looks great under ultrasound. Twenty minutes later, the patient still has sensation in the area of surgery. What is your next step?

## Block Failure

A common and frustrating "complication" with nerve blocks is failed blocks or incomplete blocks. Reasons may include incorrect block for the surgery, incorrect placement, incorrect dosage, and varying patient anatomy and innervation. **Even in the most skilled hands, some blocks fail.** It is about knowing your contingency plan. Here we present some common scenarios.

## Salvage Blocks for the Upper Extremity

### Shoulder Surgery

The classic block for shoulder surgery is the interscalene block and should provide complete analgesia and muscle weakness to the shoulder. In case of failure, patterns of residual sensation can hint at which block to do next.

**Superior shoulder pain may indicate the need for a superficial cervical plexus block.** The skin medial to and over the acromion is innervated by the supraclavicular nerve (C3–4), a branch of the cervical plexus. This nerve is usually blocked with an interscalene approach as local anesthetic spreads to the prevertebral fascia and the cervical plexus. Without this spread, the patient will need to be supplemented with a superficial cervical plexus block, a simple field block. Identify the sternocleidomastoid (SCM) muscle, mastoid process, and the clavicle. Inject a local anesthetic (0.5% ropivacaine in our case with a 1.5-in 25G needle) superficially to produce a visible

skin wheal along the lateral border of the SCM, aiming at the clavicle. But stop before you cause a pneumothorax please!

**Pain in the medial upper arm with shoulder pain may signify the need for intercostobrachial supplementation.** The intercostobrachial nerve, a cutaneous branch of the T2 intercostal nerve, innervates the upper medial arm and variably the shoulder. The intercostobrachial nerve will not normally be numbed by interscalene block as it receives minimal contributions from the brachial plexus. Most patients tolerate shoulder surgery well without supplemental blockade of this nerve but patients may occasionally need medial arm supplementation. In addition, blockade of the intercostobrachial nerve is also usually necessary for surgeries performed on the proximal arm or when an arm tourniquet is required. It may be blocked with superficial distribution of local anesthetic as evidenced by a longitudinal skin wheal over the entire medial aspect of the arm just distal to the axilla. We recommend about 5 to 10 mL of 0.5% ropivacaine with a 1.5-in 25G needle for these field blocks.

**A suprascapular nerve block and axillary nerve block may be appropriate for significant deep shoulder pain.** The suprascapular nerve (C4–6) branches off the brachial plexus and supplies innervation to the posterior shoulder capsule, acromioclavicular joint, subacromial bursa, and coracoclavicular ligament; the axillary nerve also supplies innervation to the shoulder joint as well as innervating deltoid and teres minor. Both the suprascapular nerve and the axillary nerve normally branch off the brachial plexus below the level of the trunks and so are blocked by an interscalene block. However, in the case of a failed interscalene block, or in situations in which the traditional interscalene block is to be avoided, these blocks may be able improve deep shoulder pain. A variety of landmark and/or ultrasound techniques have been described for blocking these nerves and are described in the references below. The suprascapular nerve can be identified by ultrasound immediately medial to the suprascapular artery in the suprascapular notch. In some cases, only the artery can be seen; sometimes no structures can be identified. Therefore, a suprascapular block is an advanced regional technique, and we recommend appropriate training before attempting in a failed block setting.

**Finally, the arthroscopic portals for arthroscopic shoulder surgery are often inserted outside the cutaneous distribution of the interscalene block and may require superficial local anesthetic supplementation.** This finding is especially common for the posterior port. Your surgeon should be able to easily accommodate this request once he/she identifies his/her preferred port placement.

## Forearm/Hand Surgery

Supraclavicular, infraclavicular, and axillary blocks can all be used for forearm or hand

surgery. These brachial plexus blocks should consistently anesthetize all C5–T1 areas; axillary blocks classically require musculocutaneous nerve supplementation. Supraclavicular blocks may fail due to the dorsal scapular or transverse cervical artery preventing local anesthetic spread around the brachial plexus. For infraclavicular blocks, the local anesthetic may not adequately spread to all branches or can spread to the thoracoscapular space, a soft tissue space with no distribution to the brachial plexus. Axillary blocks require multiple needle redirections, and individual nerves may not receive adequate local anesthetic. When any of these blocks fail, the following supplemental blocks can be valuable.

The distal nerves of the brachial plexus include the ulnar, median, and radial nerves; these may be identified by ultrasound immediately proximal to the elbow (for the radial nerve) and immediately distal to the elbow (for the median and ulnar nerve.) After an incomplete upper-extremity block, the nerves can be targeted individually depending on the exact location of the patient's pain. Just distal to the elbow, the medial nerve is medial and deep to the radial artery and often close to the midline. The ulnar nerve is medial to the ulnar artery at this level. The radial nerve is easily identified just superior to the elbow lying in between the biceps and triceps muscles. We recommend using the ultrasound transducer to trace these nerves proximally and distally in the forearm to adequately identify them from the multiple tendons and vessels in the forearm. By targeting specific peripheral nerve distributions with smaller volumes instead of repeating the original block, approximately 5 to 10 mL, the risk of excessive local anesthetic administration is minimized. These distal blocks can be used not only as a salvage technique but also as a primary regional approach.

Blockade of cutaneous nerves, including the lateral cutaneous and medial cutaneous nerves of the forearm, result in anesthesia of the cutaneous surfaces of the forearm. These blocks are simple field blocks and may be important when, during an axillary block, a separate musculocutaneous nerve block was not performed or failed. Local anesthetic should be injected subcutaneously on the volar surface of the arm, just below the elbow crease, to block both these nerves. We recommend 0.5% ropivacaine with a 1.5-in 25G needle for field blocks.

## TAKE HOME POINTS

- There are multiple reasons for block failure including incorrect block for the surgery, incorrect placement, incorrect dosage, and variations in patient anatomy and innervation. Patterns of residual sensation can guide a practitioner to the best supplemental technique.
- The brachial plexus innervates most of the upper extremity. However, there are

multiple nerves that innervate the shoulder, arm, and hand that do not originate in the brachial plexus and may require supplementation.

- When a more proximal block is incomplete, consider selectively blocking the distal components. Blocking distal components of the brachial plexus can also be used as a primary regional technique.
- When supplementing blocks, keep the total dosage of local anesthetic under maximum limits.

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# Salvage Blocks for Incomplete Lower Extremity Blocks

Joelle Karlik, MD and Andrew Neice, MD

A 69-year-old female with moderate COPD and morbid obesity presents for a right total knee arthroplasty (TKA). You perform the TKA under general anesthesia and an adductor canal block. The block looks great under ultrasound, and she had numbness to light touch on her distal medial thigh. After surgery, the patient wakes up with significant right posterior knee pain. What's your next step?

## Block Failure

A common and frustrating "complication" with nerve blocks is failed blocks or incomplete blocks. Reasons may include incorrect block for the surgery, incorrect placement, and incorrect dosage. In addition, the innervation of the hip, knee, and foot have varying contributions from multiple nerves. Furthermore, there is considerable variability of cutaneous innervation between the femoral, sciatic, and obturator nerves as well as their distal branches. Therefore, even if your original block is working well, aberrant anatomy may still cause inadequate analgesia and require supplementation.

## Salvage Blocks for the Lower Extremity

### Hip Surgery

The hip joint is innervated by the obturator, femoral, sciatic, and other nerves, making complete blockade of hip pain difficult without the use of neuraxial techniques. Hip surgeries are most commonly performed with spinal or epidural block or under general anesthesia with no block. However, regional blocks can be useful in patients with excessive postoperative pain.

Lumbar plexus blocks can provide complete analgesia to the hip joint but are often considered technically difficult and have been associated with a variety of serious complications. Fascia iliaca blocks and three-in-one blocks are relatively technically easy for providers already familiar with femoral blocks. In theory, these blocks deliver

local anesthesia to multiple nerves innervating the hip joint and overlying skin. The actual degree of local anesthetic spread and resulting blockade remains controversial and can be variable even with the same provider. Nevertheless, empirically patients tend to get some reduction in discomfort from these blocks although complete relief is not expected. We tend to favor larger volumes of dilute local anesthetic for these blocks like 40 mL of 0.2% ropivacaine.

For superficial pain, block of the lateral femoral cutaneous nerve can provide analgesia to the anterolateral thigh. There is significant anatomical variation and sensory coverage, so ultrasound-guided identification of the nerve may be particularly valuable for successful blockade. Ultrasound examination should focus on the lateral edge of the sartorius muscle and the nerve just lateral to the muscle border. Successful placement and injection should show local anesthetic spread between the tensor fascia lata and the sartorius muscle; only 5 to 10 mL of local anesthetic should be necessary.

## Knee Surgery

The knee joint is largely innervated by the femoral nerve but has sciatic and obturator contributions. The nerve is easily identified on ultrasound immediately lateral to the femoral artery; tilting the transducer may improve your view. Local anesthetic should spread around the femoral nerve lifting it off the medial iliopsoas muscle and/or lateral to the femoral artery. However, full circumferential spread is not required for a successful block. After knee surgery, patients with a successful femoral or adductor canal block may have postoperative pain and need supplementation.

If the pain is from the posterior portion of the knee, consider adding a sciatic single shot block for analgesia in that area. A high popliteal or infragluteal sciatic block is appropriate if the patient can position themselves either lateral or prone. If not, an anterior transgluteal sciatic block can be done in the supine position. With an ultrasound, the sciatic nerve should be visualized between the gluteus maximus and quadratus femoris muscles at the infragluteal level. If there is difficulty visualizing the nerve, try tilting the transducer and/or tracking the sciatic nerve up from the popliteal fossa. As you reach the popliteal fossa, the sciatic nerve will appear posterior to the biceps femoris (lateral) and semitendonous and semimembranosus (medial). Local anesthetic spread should be seen on the superior and inferior sides of the nerve and may require multiple redirections and injections.

If the pain persists and is medial, then supplementing with an obturator block may be appropriate. Knee innervation by the obturator nerve is variable and therefore routine use of the obturator block does not result in improved analgesia in all patients having knee surgery. The most consistent area of cutaneous innervation of the obturator nerve is the posteromedial knee. Obturator blockade should only be considered after

appropriately blocking the femoral and sciatic nerves. With the ultrasound at the inguinal crease, the obturator nerve can be individually blocked under ultrasound after identifying its two branches. The anterior branch should lie between the adductor brevis and pectineus muscles; the posterior branch lies in fascia between the adductor brevis and magnus muscles. Local anesthetic must be distributed in the fascial planes and not in the muscles for a successful block. This block often requires multiple needle redirections as well.

## Lower Leg and Foot Surgery

The primary innervation of the lower leg is the sciatic nerve, although a small strip of cutaneous sensation is provided by the saphenous branch of the femoral nerve. The division of the sciatic nerve into the tibial and common peroneal nerves can occur at variable distances from the popliteal crease. Occasionally, an anesthesiologist will confuse more distal branching with the proximal split, resulting in a block that spares either the tibial or common peroneal distribution. The sciatic block also is relatively sensitive to the exact placement of local anesthetic—injections outside the epineural sheath generally do not give adequate blocks.

If the patient is having pain in the sciatic distribution, it is reasonable to either repeat the sciatic block, or if a single branch is solely responsible for the patient's pain, selectively block one of the branches. The tibial and common peroneal nerve can be identified at the popliteal fossa and selectively blocked under ultrasound guidance. Distal injection after the branching point minimizes the need for larger doses of local anesthetic and decreases the risk of local anesthetic overdose or toxicity. Alternatively, if the surgery is on the foot, an ankle block can be performed.

If a patient is having superficial medial lower leg or ankle pain in the saphenous distribution, consider supplementing with an adductor canal or saphenous nerve block. Above the knee, the saphenous nerve pierces the fascia lata between the sartorius and vastus medialis tendons. The nerve may not be visible; only 5 to 10 mL of local anesthetic distributed around the femoral artery within the adductor canal is necessary for a successful block. Adductor blockade has a higher rate of success but can affect strength in the vastus medialis muscle and impair ambulation. The saphenous nerve can also be blocked at more distal levels. Below the knee, the nerve is medial and subcutaneous, close to the great saphenous vein. At the ankle, the nerve is medial to the saphenous vein posterior to the medial malleolus. At these distal levels, simple field blocks with subcutaneous infiltration will result in a successful block.

### TAKE HOME POINTS

- There are multiple reasons for block failure including incorrect block for the surgery, incorrect placement, incorrect dosage, and variations in patient anatomy and innervation. Patterns of residual sensation can guide a practitioner to the best supplemental technique.
- Due to the multiple nerves innervating the hip, hip surgery is best done under general, spinal, or epidural anesthesia. Peripheral nerve regional techniques may be valuable for postoperative pain.
- A femoral nerve block is often adequate for knee surgery. With continued postoperative pain despite a successful femoral block, consider sciatic and obturator blocks, respectively.
- To avoid a failed sciatic block at the popliteal level, scan proximally and distally until the branching point is identified. Epineural sheath injection proximal to the branching point should ensure that both components, common peroneal and tibial, are anesthetized by the injection.
- When supplementing blocks, keep total dosage of local anesthetic under maximum limits.

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# More Than a Stick and a Burn: Local Anesthetic Systemic Toxicity

Charles Jeremy Bengson, MD and Brandon Michael Togioka, MD

A 78-year-old male presents to you for an elective removal of a large ganglion cyst on his right hand. The surgeon says, "Let's do a Bier block!" After reminding yourself of what that is, but forgetting to look up how much local anesthetic to inject, you establish peripheral IV access and inject 40 mL of 1% lidocaine. The case is complete before your charting and you release the tourniquet. Oh my! The patient complaints of feeling "woozy," he starts to jerk involuntarily and passes out. The blood pressure cuff is cycling to no avail and you are not getting a reading. What happened? What do you do now?

Local anesthetics (LAs), popularly known as "numbing medicine," can be administered intravenously, topically, subcutaneously, around nerves, or centrally to block the spinal cord (a spinal) or nerve roots (an epidural). Regardless of where they are administered they produce their desired effect by blocking voltage-gated sodium channels on nerve cell membranes. This impedes action potentials, stops nerve conduction, and thwarts message transmission. **Also, regardless of where LAs are administered, some always ends up in the blood stream.** If enough is absorbed Local Anesthetic Systemic Toxicity (LAST) can occur leading to cardiovascular collapse and death. We will walk you through the unique pharmacologic characteristics of LAs, identify risk factors for LAST, describe how to diagnose LAST, and lastly review current treatment recommendations. We even created a very cool mnemonic that we believe highlights the core aspects of LAST treatment.

## Local Anesthetic Pharmacology

LAs are classified by their basic chemical structure. The esters (cocaine, procaine, tetracaine, and chloroprocaine) are primarily hydrolyzed in the plasma by cholinesterases, whereas the amides (lidocaine, mepivacaine, prilocaine, bupivacaine,

etidocaine, ropivacaine, and levobupivacaine) undergo biotransformation in the liver. Are you surprised that cocaine is an LA?

Three important pharmacodynamic properties (pharmacodynamics refers to the effect of a drug on the body whereas pharmacokinetics refers to how the body affects the drug) of LAs dictate their potential for toxicity:

**1)** More lipid soluble LAs have an easier time diffusing through nerve cell membranes and blocking sodium channels, consequently they are more potent. For example, bupivacaine is more lipophilic, more potent, and more likely to cause toxicity than lidocaine.

**2)** The onset time of a drug is determined by its ionization constant (pKa), or the pH at which the quantity of ionized and nonionized drug is equal. All LAs have a pKa >7.4 (physiologic pH), and thus are mostly present in ionized form. The closer the pKa of an LA to physiologic pH, the more LA is present in nonionized form allowing more drug to diffuse across the nerve cell membrane and block sodium channels. For example, the pKa of mepivacaine is lower than the pKa of bupivacaine and consequently the time of onset is faster.

**3)** The duration of action of an LA is determined by how long it binds to plasma proteins (a proxy for sodium channel binding). For example, bupivacaine is highly protein bound and also one of the longest-acting LAs.

## Properties of Commonly Used Local Anesthetics

| Class | Local Anesthetic | Time to Onset | Duration of Action | Plasma Half-Life | Relative Potency | pKa | Maximum Dose (mg/kg) |
|---|---|---|---|---|---|---|---|
| Esters | Procaine | Long | Short | – | 1 | 8.9 | 12 |
| | Tetracaine | Long | Long | – | 8 | 8.4 | 3 |
| | Chloroprocaine[a] | Short | Short | <30 sec | 3 | 9.1 | 12 |
| Amides | Lidocaine | Short | Intermediate | 1.6 hr | 2 | 7.8 | 4.5 (7 with epi) |
| | Mepivacaine | Short | Intermediate | 1.9 hr | 1.5 | 7.7 | 4.5 (7 with epi) |
| | Prilocaine | Short | Intermediate | 1.5 hr | 1.8 | 8.0 | 8 |
| | Bupivacaine | Intermediate | Long | 2.7 hr | 8 | 8.1 | 3 |
| | Etidocaine | Short | Long | 2.6 hr | 8 | 7.9 | – |
| | Ropivacaine | Intermediate | Long | 1.8 hr | – | – | 3 |
| | Levobupivacaine | Intermediate | Long | – | – | – | – |

[a]Chloroprocaine has a short time of onset despite its high pKa because it is typically given in very high concentrations due to its low systemic toxicity, thus overcoming its higher pKa. (Adapted from Felice KL, Schumann HM. Intravenous lipid emulsion for local anesthetic toxicity: A review of the literature. *J Med Toxicol.* 2008;4(3):184–191; Butterworth JF, Mackey DC, Wasnick JD. Morgan & Mikhail's Clinical Anesthesiology. 5th ed. McGraw Hill Education; 2013:271–272.)

## Risk Factors for LAST

It is standard of care to check for aspiration of blood before injecting LA; however, this does not prevent all LAST as it can occur even when LA is not directly injected into a vessel. The following factors influence the likelihood of LAST: type of LA administered; site of administration; patient age; dosage; pregnancy; as well as kidney, liver, and heart dysfunction.

Injection of LA into more vascularized tissue results in more rapid uptake. This is shown in the diagram below. To help decrease systemic uptake of LA, epinephrine (which causes vasoconstriction and delays systemic absorption) is sometimes added as an adjunct.

## Rate of Systemic Absorption (Fastest to Slowest)


Adapted from Wolfe JW, Butterworth JF. Local anesthetic toxicity: Prevention and treatment. Curr Rev Nurs Anesth. 2011;34(2):13–24. With permission.

Unfortunately, staying below the recommended maximum dose for an LA will not prevent all cases of LAST. This is because other factors come into play. Patients at the extremes of age, namely infants (low weight) and the elderly (low plasma protein concentrations leading to higher concentrations of free drug), are at especially high risk

for LA toxicity. In addition, patients with significant kidney and liver dysfunction have reduced clearance of amide LAs putting them at higher risk for LAST. Similarly, patients with heart failure may require a reduction in LA dosing due to a decrease in hepatic blood flow and subsequent clearance. Lastly, dose reductions are recommended in pregnant women due to their increased sensitivity to LAs combined with reduced plasma protein concentrations.

## Clinical Presentation of LAST

Signs and symptoms of LAST will usually manifest in the central nervous system (CNS) first followed by the cardiovascular system. Early signs of LA toxicity in the CNS include tinnitus, lightheadedness, dizziness, perioral numbness, a metallic taste, anxiety, agitation, drowsiness, and/or confusion. If these signs are not recognized, late manifestations can include obtundation, coma, seizure activity, and respiratory arrest.

Since our patients are often under general anesthesia, the initial signs of CNS toxicity may not be seen. In such circumstances, the presenting symptom from LAST may be early cardiovascular toxicity (e.g., tachycardia and hypertension). Prolonged exposure of heart muscle to LAs can lead to bradycardia, conduction abnormalities, and arrhythmias. Even longer exposure can lead to cardiovascular collapse and death.

## Signs and Symptoms of Local Anesthetic Toxicity

| | Neurologic | Cardiovascular |
|---|---|---|
| Early | Tinnitus/lightheadedness/dizziness | Initially hyperdynamic (hypertension, tachycardia) |
| | Oral paresthesia/metallic taste | Bradycardia |
| | Nystagmus/diplopia | Conduction abnormalities (increased PR interval, AV block, widened QRS, T wave changes) |
| | Restlessness/agitation | Ventricular arrhythmias (PVCs, VT, VF, Torsades de pointes) |
| | Drowsiness/confusion | Progressive hypotension |
| Late | Obtundation/coma | Cardiovascular collapse |
| | Seizures | Cardiac arrest |

Respiratory arrest

## Prevention of LAST

**If you want to avoid LAST, memorize the maximum recommended doses and establish good habits.** All patients receiving LAs should have ASA monitors placed and resuscitation equipment available during and after the procedure (LAST can present up to 30 minutes after injection), which in this case means an AED and lipid emulsion therapy. To prevent accidental systemic overdose, the American Society of Regional Anesthesia and Pain Medicine (ASRA) emphasizes using the lowest possible dose to produce the desired effect and slowly injecting LA using an incremental aspiration and injection technique (no more than 3 to 5 mL aliquots with 15 to 30 seconds between injections).

**Using ultrasound guidance when performing regional blocks may be effective in visualizing needle/catheter position, but it has not been shown to reduce the incidence of LAST.** Important! We know that the introduction of flexible, wire-reinforced catheters has made intravascular cannulation less likely, but test doses are still recommended when placing epidurals. A common test dose utilizes 10 to 15 μg of epinephrine which should increase heart rate by >10 bpm and/or increase SBP >15 mm Hg within 60 seconds.

While regional anesthesia techniques are primarily performed by anesthesiologists, keep in mind that surgeons and nurses also administer LAs and that it is the cumulative dose that matters. A common question that we hear is how to determine the maximum dose when combining different LAs. The answer is that toxicity is additive. For example, let us say you have a 100 kg person and you inject 150 mg of bupivacaine (50% of the max dose) and 225 mg of lidocaine (50% of the max dose), the sum is 100% and the patient is now at their limit.

## Treatment and Management of LAST

If you are the unfortunate soul that witnesses LAST, keep in mind that you do not need to utilize your entire arsenal for all symptoms associated with systemic LA uptake. For instance, mild CNS symptoms such as tinnitus and lightheadedness may be treated with reassurance and watchful waiting.

In patients with severe LAST, airway management and control of seizure activity take precedence. Airway management is important because hypoxia, hypercapnia, and acidosis all exacerbate the toxic effects of LAs. However, once you get that airway, avoid hyperventilation and hypocapnia as this will lower the seizure threshold. Benzodiazepines are your first-line option for seizures associated with LAST. Of note,

although propofol looks like lipid emulsion therapy, it is not. Propofol is discouraged during the treatment of LAST because the dose required to administer sufficient therapeutic lipid significantly increases the risk of hemodynamic instability. Anticonvulsants, such as phenytoin and fosphenytoin are similarly not first-line agents because they can act on sodium channels in the heart and potentiate the effects of LAs.

**Proper treatment of arrhythmias in patients with LAST is different from what is taught in ACLS.** First, traditional ACLS dosing of epinephrine should be avoided in favor of using the lowest effective dose (10 to 100 µg boluses). This is because high-dose epinephrine increased lactate production and worsened acidosis hindering the effectiveness of lipid emulsion therapy in animal studies involving bupivacaine cardiotoxicity. Similarly, if vasopressin is necessary, it is recommended to start with low doses, such as 1 to 2 units, instead of the standard ACLS dose of 40 units. Beta blockers, calcium channel blockers, and of course additional LA, such as lidocaine, should be avoided during ACLS. Amiodarone is the preferred treatment for LA-induced ventricular arrhythmias, but conclusive data regarding its effectiveness is lacking. If all other methods fail, stat initiation of cardiopulmonary bypass can support the body until enough LA is cleared for signs of toxicity to abate.

**If you remember only one thing from this lecture, please let it be that lipid emulsion therapy is the cornerstone of treatment for LAST.** Several hypotheses for its mechanism of action have been proposed. The most widely accepted hypothesis is that the lipid rich micelles sequester lipid soluble LAs away from cardiac tissue allowing cardiac muscle to recover. Current dosing guidelines for lipid emulsion therapy recommend starting with a 1.5 mL/kg bolus (lean body weight) of a 20% lipid emulsion followed by an infusion rate of 0.25 mL/kg/min. The continuous infusion should be continued for at least 10 minutes after hemodynamic stability is achieved. If the patient does not respond to the initial bolus you can give an additional bolus and increase the infusion to 0.5 mL/kg/min. The recommended upper limit for lipid emulsion therapy is 10 mL/kg over 30 minutes; however, lipid emulsion therapy is pretty safe and liberal dosing may be indicated in cases of severe LAST.

## The Management of LAST

Stop injection of additional local anesthetic and call for help
Start ACLS if indicated
  Ventilate with 100% oxygen
  Control seizures:
Administer **benzodiazepines (first line)**

Avoid propofol in patients with cardiovascular instability
Alert nearest facility with CPB capability
Initiate **20% lipid emulsion** therapy:

**Bolus 1.5 mL/kg (LBW) IV** over 1 min and begin infusion at **0.25 mL/kg/min**
For persistent cardiovascular collapse:
Repeat bolus 1–2× and increase infusion rate to 0.5 mL/kg/min
Max dose ~10 mL/kg over the first 30 min

**AVOID: CCBs, beta-blockers, or additional local anesthetic**
**REDUCE: Epinephrine dose to <1 µg/kg, minimize vasopressin doses**

**Document event at www.lipidrescue.org**
**Report use of lipid emulsion therapy to www.lipidregistry.org**

Adapted from Neal JM, Bernards CM, Butterworth JF, et al. ASRA practice advisory on local anesthetic systemic toxicity. Reg Anesth Pain Med. 2010;35(2):152–161; with permission from BMJ Publishing Group Ltd.

## Call for Help and Then Get VOCAL

The mnemonic VOCAL proposed by this author, may provide a quick memory aid, highlighting the core principles of LAST treatment:

**V**entilate
**O**xygenate
**C**PR/ACLS (if indicated)
**A**ntiseizure–Benzodiazepines (first[t] line)
**L**ipid emulsion (20%)

What happens to our patient in the clinical vignette above? By recalling this chapter, you are able to quickly diagnose LAST and start treatment. You stabilize the patient on lipid emulsion therapy and take them to the ICU. Great job!

### TAKE HOME POINTS

- When injecting local anesthetics, use the lowest effective dose administered slowly in small increments using the aspiration-injection technique.

- Consider the use of an intravascular marker (i.e., epinephrine) to assess for unintended intravascular injection.
- The worst LAST mistake you can make is to miss it. Think about it every single time you inject local anesthetic into a patient. Every single time. When you ask your patients if they are having any of the classic symptoms of LAST, **pay attention to the answers**!
- Early signs of LAST include tinnitus, lightheadedness, perioral paresthesia, a metallic taste, agitation, drowsiness, tachycardia, and hypertension. Later signs include obtundation, seizures, bradycardia, conduction abnormalities, arrhythmias, and hypotension. Untreated severe LAST can lead to cardiopulmonary arrest.
- The initial response to LAST is making sure LA administration is halted, airway management and control of seizure activity with benzodiazepines (first-line therapy).
- Consider early administration of lipid emulsion therapy 1.5 mL/kg bolus followed by 0.25 mL/kg/min infusion.

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# Lipid Rescue—Where Are We Now?

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A 28-year-old female presents for repair of a right ankle fracture after experiencing a fall while rock climbing. She is 5'6" tall and weighs 50 kg. She has a medical history of mild asthma. She has previously undergone an appendectomy at the age of 7 years old and denies any abnormal reaction to anesthesia. While receiving a preoperative popliteal block using 30 mL of 0.5% bupivacaine, the patient reports feeling dizzy and has "a weird metallic taste" in her mouth during injection. A few minutes later, she becomes unresponsive. You start treatment for a presumptive case of local anesthetic toxicity (LAST). What is the role of intralipid therapy in the treatment of LAST?

## Introduction to LAST

When local anesthetics are administered to a patient (by any route!), there is slow absorption that can lead to elevation of local anesthetic blood levels. The elevation in blood level will depend on the site of injection, the mass of drug administered, the use of epinephrine, and so forth. Alternatively, if a local anesthetic is injected directly into an artery or vein, there will be a much more rapid rise in blood level. If blood levels rise to a high enough level, signs and symptoms of systemic toxicity can occur. Local anesthetics bind to sodium and other ion channels in the head and heart, and when this channel blockade becomes significant, electrical impulse conduction is impaired, and signs and symptoms will occur.

Central nervous system symptoms are generally seen before cardiac symptoms. Local anesthetics readily cross the blood–brain barrier. Signs of CNS toxicity are dose-dependent. Early symptoms of LAST include tinnitus, circumoral numbness, metallic taste, and agitation. This can then progress to seizures and/or CNS depression (coma, respiratory arrest).

In general, much higher blood levels of local anesthetics are required to produce cardiovascular toxicity than those that produce CNS toxicity. Acute local anesthetic cardiotoxicity negatively impacts myocardial contractility, cardiac conduction, and

systemic vascular resistance. Lidocaine tends to more commonly cause myocardial depression. Toxicity from bupivacaine, levobupivacaine, ropivacaine, and etidocaine tends to manifest as ventricular dysrhythmias that are resistant to resuscitation. Bupivacaine toxicity is classically very difficult to treat—it has high affinity for myocardial sodium channels.

## Does This Patient Show Signs of LAST?

Yes! This patient reported feeling dizzy and had "a weird metallic taste" in her mouth during placement of her popliteal fossa block. A few minutes later, she became unresponsive. The metallic taste sensation argues against this just being a vasovagal episode. The fact that the symptoms occurred almost immediately would point us toward a mechanism of direct intravascular injection. And since 0.5% bupivacaine was the injected drug, she is likely to rapidly proceed to ventricular dysrhythmias and cardiac arrest. Time for us to get moving!

## Management of LAST

If signs and symptoms of LAST occur, prompt and effective airway management is crucial. Prevention of hypoxia, hypercapnia, and acidosis can halt progression to seizures and cardiovascular collapse and facilitate resuscitation.

**Start lipid emulsion therapy**—20% lipid emulsion bolus 100 mL over 2 to 3 minutes if patient is over 70 kg (or 1.5 mL/kg over 2 to 3 minutes if patient is less than 70 kg). Then continue with an infusion of 200 to 250 mL over 15 to 20 minutes if patient is over 70 kg (or 0.25 mL/kg/min if patient is less than 70 kg). Initiation of lipid therapy should be a high priority—get it started!

If circulatory stability is not attained, consider a rebolus or increasing infusion to 0.5 mL/kg/min. Continue infusion for at least 10 minutes after circulatory stability is attained.

Approximately 12 mL/kg lipid emulsion is recommended as the upper limit for initial dosing.

If seizures occur, they should rapidly be halted with benzodiazepines. If benzodiazepines are not readily available, small doses of propofol are acceptable. Although propofol can stop seizures, large doses risk depressing cardiac function. Lipid therapy itself may also help terminate seizures.

If cardiac arrest occurs, ACLS protocol is followed with the following modifications:

- If epinephrine is used, small initial doses (≤1 μg/kg) are preferred.
- Avoid vasopressin, calcium channel blockers, and β-adrenergic receptor blockers.

- If ventricular arrhythmias develop, amiodarone is the preferred treatment (treatment with lidocaine or procainamide is not recommended.)

If the patient does not respond to ACLS and lipid therapy, prompt initiation of cardiopulmonary bypass or ECMO may be lifesaving.

## History of Lipid Therapy for LAST

Intralipid 20% is made from 20% soybean oil and was initially created to provide nutrition to those who did not have enough essential fatty acids. In 1998, Weinberg discovered that it could also be used to treat local anesthetic toxicity in rats. In 2006, Rosenblatt reported the first successful clinical use of lipid emulsion therapy in treating LAST. A patient developed cardiac arrest shortly after a nerve block with mepivacaine and bupivacaine. The patient failed to respond to standard resuscitative efforts for approximately 20 minutes but achieved normal vital signs shortly after receiving a 100 mL bolus of lipid emulsion. Since then, lipid therapy's utility in reversing the neurologic and cardiac effects of local anesthetic toxicity has been demonstrated in multiple case reports and animal studies.

Initially, lipid therapy was a curiosity, and it was suggested that it could be tried if standard resuscitative attempts had failed. However, case reports and experience lead to the conclusion that the therapy was relatively nontoxic, and should be initiated early in the treatment of LAST. The 2010 ASRA Practice Advisory on LAST made the recommendation to "consider administering at the first signs of LAST, after airway management." However, on the strength of further experience and data, the 2017 ASRA Practice Advisory on LAST now states "we now unequivocally recommend lipid emulsion therapy soon after airway management in any LAST event that is judged to be potentially serious."

## Practical Aspects of Lipid Therapy

Lipid therapy is not helpful if you do not have easy and quick access to it. We stock a "Lipid Rescue Kit" on our block carts—-which includes a bag of 20% intralipid, intravenous tubing, alligator clip, and an instruction sheet (available at www.lipidrescue.org).

## How Does Lipid Rescue Work?

It was initially proposed that lipid rescue might work by creating a intravascular "lipid sink" which would absorb local anesthetic out of the circulation and thus result in a decrease in tissue levels of local anesthetic. It is now believed that lipid therapy may have multimodal benefits. Recent research has led to a new concept—that lipid

emulsion works as a dynamic carrier to scavenge local anesthetic away from high blood flow organs that are most sensitive to LAST (i.e., the heart and brain) and redistribute it to organs that store and detoxify the drug (i.e., muscle and liver). It has also been proposed that lipid emulsion may have a direct cardiotonic effect on the heart, leading to improved contractility and cardiac output. And lastly, there may be a postconditioning effect that reduces myocardial damage after resuscitation is successful.

## Side Effects and Complications

Use of intralipid is associated with few side effects and complications. Although rare, there have been reports of headaches, dizziness, nausea/vomiting, flushing, and sweating. In addition, a few cases of pancreatitis and deep vein thrombosis have been reported. It has been reported that lipid therapy can interfere with laboratory testing. Lipid therapy has also led to fat deposition and blood clots in extracorporeal membrane oxygenator circuits.

## Other Uses for Intralipids

Recently, lipid rescue is being assessed for its ability to treat toxicity from lipophilic agents such as β-blockers, calcium channel blockers, herbicides, parasiticides, and a variety of psychotropic agents. In a study involving rats that received oral parathion, those that received lipid emulsion infusions 20 minutes after exposure to the poison had delayed time to apnea. Furthermore, there have been case reports indicating complete reversal of cardiogenic shock after administration of high-dose insulin and intralipid in patients with toxic levels of β-blockers and calcium channel blockers. Additional studies are needed and no formal recommendation has been provided regarding the use of intralipid in other lipophilic drug toxicity.

### TAKE HOME POINTS

- Local anesthetics work by inhibiting sodium channels; toxic levels can affect ion channels in the heart and central nervous system.
- Intralipid therapy has been successful in reversing the cardiac and neurologic manifestations of local anesthetic toxicity. It is now an accepted therapy.
- The first line in managing local anesthetic toxicity is maintaining the airway and avoiding hypoxemia, hypercapnia, and acidosis. Lipid therapy should also be immediately instituted.
- A modified version of ACLS is instituted as required (low-dose epinephrine; no vasopressin, lidocaine, or procainamide).
- In the future, intralipid may be useful in treating toxicity from drugs like calcium

channel blockers, β-blockers, organophosphate poisoning, and other lipophilic drugs.

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# A Patient Who Is Planned for Spinal Anesthesia Asks "Can This Paralyze Me?" What Are the Facts and What Do You Say?

Raymond G. Graber, MD

## Introduction

Neuraxial anesthetic techniques provide a great alternative to undergoing general anesthesia for many surgical procedures, and are also used to produce excellent analgesia for labor and delivery and postoperative surgical pain. We perform these procedures on countless patients with great results and minimal consequences. However, patients are rightly concerned about the potential adverse effects of any procedure we do, so at some point in your career, you may be asked the question: "What is the risk that this spinal (or epidural) will paralyze me?" Let us dive into this topic, and see what the literature says.

## What Is the Incidence of Injury?

One of the largest studies to try to examine the incidence of spinal cord injury dates back to 2004, when Moen et al. reported on the incidence of severe neurologic complications that occurred in Sweden from 1990 to 1999. Severe neurologic complications included epidural hematoma, epidural abscess, meningitis, cauda equina syndrome, traumatic cord injury, and so forth. The overall incidence was 127 severe complications in 1,710,000 estimated patients (1:13,464 or 0.007%). To break this down further, there were 56 severe complications in 1,260,000 spinal patients (1:22,500), and 71 severe complications in 450,000 epidural or combined epidural spinal (CSE) patients (1:6,338). There are many other studies out there, but this study is a good representation of the current data.

## What Are the Potential Causes of Spinal Cord Injury?

Although rare, spinal cord or nerve root injury can occur as a consequence of neuraxial

techniques. Most of the injuries are due to one of the following causes: direct trauma, compression from hematoma, compression from abscess, neurotoxic effects of local anesthetics, and spinal cord ischemia. There are also conditions that may predispose to some of these mechanisms of injury, including bad technique, spinal stenosis, immunosuppression, pre-existing neurologic disease, and abnormal coagulation. Here are the data from neuraxial anesthesia in the 1990s in Sweden by injury type:

| | Epidural and CSE | Spinals |
|---|---|---|
| Epidural hematoma | 25/450,000 (1:18,000) | 8/1,260,000 (1:157,500) |
| Cauda equina syndrome | 12/450,000 (1:37,500) | 20/1,260,000 (1:63,000) |
| Epidural abscess | 12/450,000 (1:37,500) | 1/1,260,000 (1:1,260,000) |
| Meningitis | 6/450,000 (1:75,000) | 23/1,260,000 (1:54,782) |
| Spinal cord trauma | 8/450,000 (1:56,250) | 1/1,260,000 (1:1,260,000) |
| Paraparesis | 3/450,000 (1:150,000) | 1/1,260,000 (1:1,260,000) |
| Other | 5/450,000 (1:90,000) | 2/1,260,000 (1:630,000) |
| Total | 71/450,000 (1:6,338) | 56/1,260,000 (1:22,500) |

Using this data, and removing cases of meningitis and "other" from the calculations, we can calculate a risk of paralysis of 1: 7,500 for epidurals, and 1:40,645 for spinals. The Swedish investigators also pointed out that there were lower and higher subgroups within the general population. For example, the young and healthy obstetric population had a risk of paralysis of 1:50,000. The elderly female having a total knee replacement had a risk of subdural hematoma of 1:3,600. (Note: The first Swedish neuraxial anticoagulation guidelines were not established until 2001.)

An analysis of the ASA Closed Claims Database from the 1980s and 1990s again demonstrated the existence of catastrophic events secondary to neuraxial techniques. Included in this database were 81 cases of cardiac arrest, 49 cases of paraplegia, and 200 cases of death or permanent brain damage. The causes of paraplegia included epidural hematoma, epidural abscess, anterior spinal artery syndrome, and spinal cord infarct. This database does not allow us to draw any conclusions about incidence, but it does verify the existence and severity of these bad outcomes.

Granted, these data are a little old. Once could argue that outcomes might be better in this day and age, since we have better monitors, modern antiseptics and dressings, better understanding of the risk factors, and practice advisories to guide our care. However, patients in the United States are also more elderly, have more comorbidities

(such as obesity), are exposed to more antibiotic resistant bacteria, and are administered more blood thinners than ever before. Thus, it is not clear that outcomes are actually any better.

We will now discuss some of the risk factors and preventive strategies for these complications, so that you are aware of the potential landmines and do what you can to avoid bad outcomes in your practice.

## Direct Trauma

The spinal cord ends at about the L1 body to L1–2 interspace level in adults. So when placing a spinal, the conventional recommendation is to place your needle at L2–3 or below. Tuffier's line (the line joining the peak of the iliac crests) typically crosses through about L4, and is the landmark most people use to count interspaces. However, there always is an anatomic variation, and a very small group of patients will have spinal cords that terminate as low as L4–5. In other patients, it can be difficult to palpate the iliac crest, and as a result the interspaces can be miscounted. So, in the right patient, there is a potential to have a cord that ends lower than normal, and an entry point higher than planned because of misinterpretation of interspace level. Thus, you have a setup for direct trauma.

With epidurals, we do not worry about the level where the cord ends, since we are further away from the cord, and this allows us to place catheters in locations that correlate to the important dermatomes of the surgical procedure (e.g., midthoracic for a thoracotomy). However, wet taps are possible, so any paresthesia during placement should result in pullback of a needle or a catheter.

Historically, early practitioners of spinal anesthesia did not follow the "L2–3 or below" rule. For example, in 1909, Thomas Jonnesco described performing 103 cases with T1–2 spinals. He successfully performed operations such as thyroidectomies, mastectomies, and craniectomies—that is one high spinal! However, there were complications, not well described, because this was in the era when people were not collecting data on such things. At some point, the potential for traumatic injury was better understood. In a 1928 symposium on spinal anesthesia, authors were recommending performing spinals at L2–3 or below as a standard practice.

To prevent direct trauma-related injuries, the practitioner must use careful identification of interspaces, and use careful, controlled, slow advancement of needles. You can be the most efficient and fast provider out there, but this is one time you take a deep breath and slow down.

## Compression From Hematoma

There are blood vessels in the epidural space—so there is potential to nick something

during neuraxial procedures. In the average patient who clots normally, this is almost never a problem. The problem arises when you have a patient with preexisting coagulopathy, or one who gets anticoagulated postprocedure. Because of the emphasis placed on prevention of thrombosis-caused morbidity and mortality (e.g., deep vein thrombosis, pulmonary embolism, atrial clots in patients with atrial fibrillation, stent thrombosis, and mechanical valve thrombosis), many patients will present on blood thinners, or will be anticoagulated postop. There are also clotting defects related to disease states or congenital causes (e.g., preeclampsia-induced thrombocytopenia, liver dysfunction induced decreased production of clotting factors, haemophilia). Because this is such a prevalent issue, the American Society of Regional Anesthesia (ASRA) has come up with guidelines for the management of neuraxial anesthesia in patients on anticoagulants. These are updated regularly, as new data come out and new drugs are developed, and published on their website.

To prevent hematoma-related injuries, you must know your patient's medication and medical history, and get updated labs as needed. Follow the ASRA guidelines. Use careful technique. Remember, neuraxial techniques are beneficial, but not mandatory.

## Compression From Abscess

Anytime you place a needle or catheter, there is the potential to contaminate the epidural space or CSF with bacteria. When catheters are left in place, they will almost always get colonized with skin flora if left in place long enough. Patients who are bacteremic while a catheter is in place also have the potential to seed the catheter through a hematogenous spread. Some patients are immunosuppressed, and may have higher risk for infection. ASRA has published guidelines on prevention, diagnosis, and management of infectious complications of neuraxial procedures.

To prevent neuraxial infectious complications, use a careful antiseptic prep and sterile technique. Avoid placing through skin that is potentially infected. If the patient is potentially bacteremic, consider preprocedure antibiotic therapy. Use sterile occlusive dressings. Shorter durations of catheterization are better than longer (old data suggest that many catheters in general are colonized by 3 days). This is especially important in patients that are immunosuppressed or bacteremic. Remove catheters when there is an unwitnessed disconnect.

## Neurotoxic Effects of Neuraxial Drug Delivery

The typical local anesthetics and opioids used in neuraxial techniques are safe as long as they are not used in excessive doses and are administered with a good technique. However, in the past years, there have been issues related to contaminants, catheters, and preservatives.

In 1947, there were two patients (Woolley and Roe) who became paraplegic after spinal anesthesia for minor surgery at the Chesterfield Royal Hospital in England. The spinals were administered by the same practitioner on the same day. There were two different theories about the etiology of these catastrophic injuries: (1) The local anesthetic vial was sterilized by soaking in phenol—it was hypothesized that microcracks in the vial led to contamination of the local anesthetic; (2) The needles were cleaned and reused. There is speculation that the needles were contaminated with residual acidic cleaning chemical. These cases received major news coverage at the time in England, and resulted in a major loss in faith in the safety of spinal anesthesia.

In the late 1980s, continuous spinal anesthesia came into vogue. The theory was that local anesthetic could be titrated in (thus limiting hemodynamic changes), and could be redosed (to extend duration). To reduce the risk of spinal headache, microcatheters were developed (28G catheter via 22G spinal needle, and 32G catheter via 24G spinal needle). Shortly after these came into use, cases of cauda equina syndrome were reported. In retrospect, what probably happened was that the catheters were threaded in a caudal direction rather than cephalad. When a local anesthetic was dosed (typically lidocaine), the level did not come up (the local anesthetic pooled sacrally). This led practitioners to keep dosing more local anesthetic—hoping to raise the level of block. Unfortunately, in some cases, toxic levels of local anesthetic lead to the development of cauda equina syndrome. Eleven cases of cauda equina syndrome were noted over a 2.5-year period. The FDA removed these microcatheters from the market in 1992.

In the early 1980s, there were a few case reports implicating chloroprocaine as being potentially neurotoxic. The common scenarios were a planned epidural technique, but instead an inadvertent intrathecal injection of a large volume of chloroprocaine—resulting in prolonged sensory-motor deficits. Although not totally worked out, there is belief that the formulation used at the time was part of the issue-–low pH and presence of sodium bisulfite as a preservative. Chloroprocaine is now available in a preservative free form.

To prevent neuraxial neurotoxicity, we now use single use trays and drug vials. Preservative free local anesthetics are used. Take precautions to avoid getting disinfectant on the needles you will be using during the procedure. Also, allow the solution to completely dry on skin before needle placement (2 to-3 min). Use careful technique when placing epidurals. Always use test doses. If using a catheter that is placed intrathecally, limit your dosing—do not be lured into trying to fix a catheter malposition with excess dosing.

## Spinal Cord Ischemia

Perioperative ischemic spinal cord injuries are rare and more likely to be associated

with spine surgery and aortic surgery. However, it is possible to cause spinal cord injury if there are prolonged periods of hypotension. Recent data suggest that the lower limit of autoregulation for spinal cord blood flow may closer to a MAP of 60 to 65 mm Hg rather than the classically understood MAP of 50 mm Hg. The last ASRA practice advisory on prevention of neurologic complications recommends avoiding prolonged hypotension during neuraxial anesthetics (>20% to 30% below baseline mean arterial pressure [MAP] especially for 20 minutes or longer).

## Predisposing Conditions

**Spinal Stenosis:** There has been some recent discussion that significant spinal stenosis may by exacerbate conditions when neuraxial anesthesia is complicated by the development of mass lesions within the spinal canal (e.g., hematoma or abscess). For example, in the Swedish data, the elderly female having an epidural for knee replacement was the highest risk subgroup for complication – presumably because of a high incidence of spinal stenosis, along with postoperative anticoagulation. The author does not avoid spinal anesthesia when he knows a patient has significant spinal stenosis. However, I have had patients who developed worsening symptoms after placing epidural catheters – sometimes just a little inflammation around a catheter is enough to exacerbate stenosis symptoms. For that reason, I tend to avoid placing epidural catheters if I know the patient has significant stenosis.

**Preexisting Neurologic Disease:** You may have heard of the "double-crush" theory. This theory maintains that patients with preexisting neurologic disease may be at increased susceptibility for subsequent nerve injury from a secondary insult such as might occur during the perioperative period from a regional anesthetic. Preexisting neurologic conditions have historically led to recommendations not to perform regional anesthetics. The issue is complicated by the fact that some of these conditions wax and wane, and can be exacerbated by perioperative stress. In addition, we are trying to draw conclusions from a literature that mostly consists of case reports and small series. No big randomized controlled studies here. For example, a not uncommon scenario is to have a patient with a history of multiple sclerosis present for labor and delivery. The ASRA recommendations are as follows: "Anecdotal case reports and small case series suggest that neuraxial anesthesia and analgesia may be used in patients with stable neurologic symptoms without worsening their neurologic deficits. However, definitive evidence supporting this practice is lacking. Therefore, a careful discussion regarding the potential risks and benefits of performing regional anesthesia in patients with preexisting neural compromise is strongly recommended." When performing epidural techniques in patients with pre-existing disease, it is generally recommended to use lower concentrations and dose of local anesthetic and reduce or avoid use of

epinephrine. Epidural anesthesia is considered safer than spinal anesthesia because it does not deposit local anesthetic directly adjacent to the spinal cord—but I think this is based on opinion rather than on data.

## So, With All This in Mind, How Do You Answer the Patient's Question?

First of all, don't brush by it. A reasonable, serious question deserves an answer in kind. Using the Swedish data, for the population as a whole, we could estimate a risk of paralysis of 1: 7,500 for epidurals, and about 1:40,000 for spinals. However, we know that there are higher and lower risk groups within the general population and you can appropriately note for the patient if he or she is in any of these groups. For example, we do tons of labor epidurals in healthy patients—a better number to quote for this group would be 1:50,000. Indicate that you are aware of the ASRA guidelines and also take enough time to describe the steps you will take to minimize the risks of catastrophic neurologic sequelae.

### TAKE HOME POINTS

- In one large Swedish retrospective study over a 9-year period, there were 56 severe complications in 1,260,000 spinal patients (1:22,500), and 71 severe complications in 450,000 epidural or combined epidural spinal (CSE) patients (1:6,338).
- Potential causes of spinal cord injury include direct trauma, compression from hematoma, compression from abscess, neurotoxic effects of local anesthetics, and spinal cord ischemia.
- There are also conditions that may predispose to some of these mechanisms of injury, including bad technique, spinal stenosis, immunosuppression, preexisting neurologic disease, and abnormal coagulation.
- The American Society of Regional Anesthesia has developed a number of guidelines with the goals of reducing epidural hematomas, reducing infectious complications, and reducing neuraxial injury in general. These are worth reading and implementing in your practice. The most recent journal publications of these guidelines are included in the "Suggested Readings." These can also be accessed at: https://www.asra.com/advisory-guidelines.

## Suggested Readings

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# Spinals in the Lateral Position

Liora Yehushua, MD and Catherine Marcucci, MD

There are times when it is necessary to perform a spinal anesthetic in the lateral position even though it is often easier to find the anatomic midline when the patient is seated upright. Ill, frail, or overly sedated patients, and patients at risk for vasovagal reactions tolerate the lateral decubitus position better than a seated position. Many of the patients in need of spinal anesthesia have intense pain in the seated position due to trauma or their disease process (i.e., in the case of a fractured hip or perirectal abscess). Others may be quite obese and difficult to reposition quickly after placement of the spinal, so it is best that they start out lying on their side.

## Basic Positioning

Place the patient in a position that he or she can tolerate, with the operative side down when using hyperbaric local anesthetic solution, or with the operative side up if using hypobaric local anesthetics. Isobaric solutions provide a narrow dermatomal coverage at the level of the injection and last longer. If bilateral spread is required, any baricity local anesthetic can be used. The patient is then quickly rolled supine after administering the medication into the subarachnoid space. Trendelenburg or Reverse Trendelenburg position can be used to influence the spread of the block.

To perform a lateral spinal, the patient is positioned laterally with their back at the edge of the table closest to the anesthesiologist. Both the patient's shoulders and hips should be perpendicular to the bed to prevent rotation of the spine; the neck should be flexed and the knees drawn to the patient's chest in the "fetal position" as much as the patient can tolerate it. Flexing the spine this way opens up the intervertebral spaces and increases the target area for needle insertion, which is the interlaminar foramen. **Many practitioners put importance on neck flexion but evidence suggests that it does not actually affect the size of the interspinous opening. Therefore, if it is uncomfortable for the patient, the neck does not need to be flexed**. Often, an assistant is needed to help the patient assume this position and hold steady during the procedure—moving targets are tough to hit.

Visual inspection and manual palpation of bony landmarks identify the point of entry for a midline approach. When an obese patient is seated, those landmarks can be difficult to find and they may be entirely obliterated in the lateral position. Some patients may not be able to curl into the correct position to open the space between the spinous processes. Further, patients may sometimes curl up in such a way as to roll anteriorly, shifting the midline axis in terms of the vertical perpendicular plane to the operating room table.

## Understanding the Anatomy

The lateral position induces a scoliosis, especially in patients with wider hips. A pillow between the legs can be more comfortable for the patient and potentially negate the "dip" that happens in the spine in the lateral position. The effects of gravity can cause a few centimeters of "sag" of the soft tissues, especially in older or overweight patients, making it extremely easy to miss the midline. Providers who are consistently contacting bone during a midline approach are usually tapping the dependent lamina. The true midline of the patient is almost always found to be toward the nondependent side on repeated palpation and redirection of the needle.

When palpation is not possible or not successful, an ultrasound examination with the curved array ultrasound probe along the sagittal plane can identify the spinous processes. Once the midline is found, you can turn the probe along the transverse plane to find the intervertebral space. You can make marks to help you visualize the anatomy and give yourself the best chance of finding the right spot.

The paramedian approach does not depend on maintaining an open interspinous space and is much more forgiving of unintended deviations. If the patient has heavily calcified interspinous ligaments, has had previous spinal surgery, or is unable to flex the spine, the paramedian approach is also useful. Midline approach requires the needle to transverse skin, subcutaneous tissue, the supraspinous ligament, the interspinous ligament, the ligamentum flavum, epidural space, dura mater, and finally arachnoid mater. The paramedian approach involves bypassing the supraspinous and interspinous ligaments, so that the ligament flavum is the first structure to offer significant resistance to needle advancement.

For the paramedian approach, first establish the deviation of the patient's back from the plane vertical to the floor by lightly resting your palm flat against the patient's back. It is easier to determine whether you are off the vertical plane using your hand for sight and feel than to just visually gauge this. Second, place the needle about 1 to 2 cm lateral to the interspace. Most providers choose the dependent side of the spinal column, placing the needle slightly toward the "bottom" of the interspace. Finally, direct the needle 15 degrees medially and cephalad and advance until the ligamentum flavum is

transversed and the subarachnoid space is entered. One can instead use the lamina to guide placement by placing the needle 1 cm lateral to the midline but first advancing perpendicularly to the back in order to contact the lamina. Then partially withdraw the needle and increase the medial and cephalad angle in small increments in order to "walk the needle" off of the edge of the lamina and enter the spinal canal. The most common error is to direct the needle too medially, therefore crossing the midline due to underestimation of the distance to the subarachnoid space.

## TAKE HOME POINTS

- Spinal anesthetics are frequently performed in the lateral position due to disease process or the need for sedation during the procedure.
- The lateral position can make it difficult for patients to curl into the fetal position and for anesthesia providers to appreciate the bony landmarks.
- It is very common for practitioners attempting a midline approach in the lateral position to deviate a few centimeters from the midline.
- Placement of the intrathecal anesthetics can usually be easily and safely accomplished using the paramedian approach.

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# Consider the Paramedian Approach for Spinal Anesthesia in the Hip Fracture Patient

Raymond G. Graber, MD and Emily Poynton, DO

An 86-year-old female with a history of hypertension presents for open reduction-internal fixation of a right hip fracture. After discussion with the patient, a decision is made to proceed with spinal anesthesia. What approach would you use to accomplish this—midline or paramedian?

Spinal anesthesia is a technique frequently used in hip fracture surgery. However, it can be difficult to do for multiple reasons. These patients have narrower interspinous spaces as their spine shrinks with age (due to thinning of intervertebral discs). Because of pain at the fracture site, it can be painful for the patient to position for the spinal, and then maintain a flexed position. It is typical to do this in the lateral position, and it can be harder to identify the midline of spinous processes due to sagging of tissue toward the dependent side.

Although a midline approach can be utilized, the authors prefer to go straight to the paramedian approach, because of the issues described above. When using the paramedian approach, the needle is passed between adjacent lamina, rather than between spinous processes. This approach frequently offers a much larger area of access to the dura (Fig. 172.1). In the elderly hip fracture patient, the paramedian approach is often the easier and quicker approach.

**So here is what we teach and do:**

- Most patients with hip fractures will arrive in the OR in their hospital bed. It is easier on the patient if the spinal is performed on the bed rather than moving or being moved to the OR table first.
- It is less painful for the patient if he or she is positioned laterally with the fracture side up. The authors will use 0.5% bupivacaine for the spinal, which tends to clinically act mildly hypobaric—it will rise to the operative hip.
- What about sedation for positioning? We generally put monitors and oxygen on the

patient, and then give a small dose of propofol (20 to 40 mg) to "stun" the patient for the turn to the lateral position. This will allow turning and positioning, and then wears off quickly.

- Since the patient's nonoperative hip tends to sink into the mattress, we will put an IV bag under that hip to help raise it out of the mattress.
- The patient's hips are flexed up and the head down, but avoid excessive hip flexation because of the fracture.
- While in the lateral position, it is helpful to roll the nondependent side of the patient slightly forward, so that this side is leaning away from you. This makes it easier to perform the paramedian approach from the down side.
- Technique: After the patient is positioned, prepped, and draped, potential interspaces (L2–3 and below) are palpated and an interspace is chosen. The authors will make a thumb mark at the cephalad border of the inferior spinous process. A skin wheal is made at a point 1 cm lateral to the edge of the spinous process, at the level of the thumb mark, on the dependent side of the spine. The needle is introduced at this location, with a 10- to 15-degree medial angle, and a 0-degree cephalad angle. Lamina will frequently be encountered—the needle is withdrawn, and walked cephalad, eventually through the dura. Once CSF is encountered, local anesthetic is injected.
- Ultrasound approaches to paramedian spinal anesthesia are being described and studied.

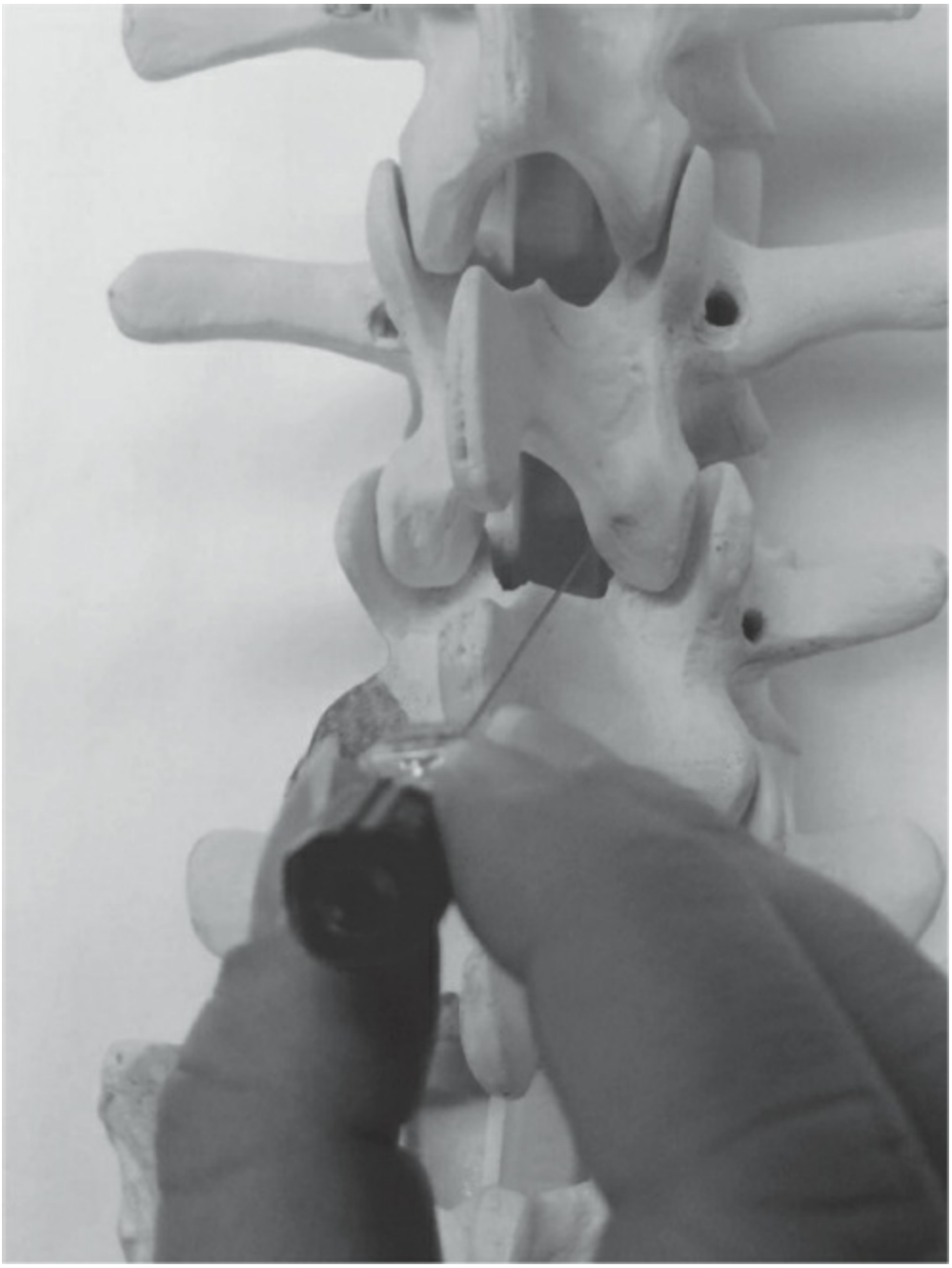

**Figure 172.1.** Demonstration of the paramedian approach, showing the spinal needle passing through the interlaminar space.

## TAKE HOME POINTS

- In the elderly hip fracture patient, changes in spine anatomy and pain-induced difficulty with positioning can make traditional midline approaches to spinal anesthesia difficult.
- In the elderly hip fracture patient, a paramedian approach to spinal anesthesia may be easier to perform than a midline approach.

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# When Is a Whisper a Cry for Help? When the Patient Has a High Block

Ryan J. Bortolon, MD and Juraj Sprung, MD PhD

Use of regional anesthesia has grown in recent years, due in large part to the benefits of improved postoperative pain management. Regional anesthesia also continues to be the preferred technique for management of pain during labor and is considered the safest approach for elective cesarean section. Despite adoption of safer regional anesthetic dosing practices, catastrophic complications from inadvertent intrathecal or intravascular injection are still reported.

## Inadvertent Intrathecal Injection

High spinal or "total" spinal block is one of the most feared complications of neuraxial anesthesia and other regional techniques. Total spinal block is typically caused by excessive cephalad spread of local anesthetic. Severity of block is variable and depends primarily on baricity and duration of local anesthetic action. Patient characteristics, such as age, height, and anatomic considerations (e.g., pregnancy) also have a role in the level of spinal block. **The most common cause of excessive anesthetic spread is unintentional dural puncture and subsequent injection of a large volume of local anesthetic intrathecally.** Mechanisms of total spinal block include the following:

- Migration of the epidural catheter into the intrathecal space after proper placement;
- Repeated spinal anesthetic administration;
- Large volume expansion of the epidural space, leading to compression of the dura;
- Intrathecal spread of an epidural bolus after a previous dural puncture;
- Unrecognized subdural placement of the epidural catheter; and
- Inadvertent injection or catheter placement into the dural sleeve surrounding the nerve root.

The onset of total spinal block may be quick or delayed, depending on the type, volume, rate of injection, and location of injection of local anesthetic. In a patient who

is awake, the first signs of high spinal block may include dyspnea, loss of speech, feeling of impending doom, or restlessness. These signs may then be followed by hypotension, bradycardia, unconsciousness, and, ultimately, circulatory (cardiac) arrest.

Anesthesiologists must keep in mind that a total spinal block may occur in patients under general anesthesia who have had epidural or peripheral nerve blocks for perioperative pain management. In these patients, a total spinal block presents only as hypotension or bradycardia intraoperatively. In the postoperative setting, these patients remain unconscious with fixed, dilated pupils and require full ventilatory support until brainstem and respiratory functions return.

## Intravascular Injection

In general, local-anesthetic toxicity results in benign transient symptoms; however, with large doses of anesthetic, central nervous system (CNS) and cardiovascular toxicity can lead to catastrophic consequences. The most common cause of local-anesthetic toxicity is unrecognized intravascular injection of bolus doses of local anesthetics from a misplaced catheter or needle during a regional anesthetic block. The surest sign of intravascular injection is aspiration of blood, but this test is far more sensitive than specific (resulting in a higher false-negative rate). Several case reports have described intravascular injection despite negative aspiration from the catheter. Most authors of these case reports suspect migration of the needle or catheter tip intravascularly as the primary cause. Others theorize that a catheter tip flush against an intravessel wall may also give a falsely negative aspirate. Less commonly, local anesthetic uptake by highly vascular tissues can lead to toxic plasma levels. Understanding the relationship between anesthetic dose, body weight, and speed of systemic absorption is important in clinical practice to help avoid high plasma concentrations of local anesthetic.

The initial symptoms of CNS toxicity may be excitatory and include tinnitus, perioral numbness, metallic taste, visual disturbances, peripheral motor twitching, and, eventually, grand mal seizures. As plasma levels of anesthetic increase, CNS depressant effects predominate, with disorientation, drowsiness, or unconsciousness being most common.

The cardiovascular effects of local-anesthetic toxicity are seen at serum concentrations of local anesthetic higher than those necessary to elicit CNS toxicity. **All local anesthetics directly depress cardiac contractility through their inhibitory action on voltage-gated sodium channels in cardiac muscle.** Local anesthetics have a variable effect on the fast-conducting tissues that predispose the heart to dysrhythmias. Although all anesthetics at high plasma levels cause dose-dependent cardiac depression, bupivacaine and tetracaine are the most potent inhibitors and are associated most frequently with severe cardiac collapse. Bupivacaine-associated cardiac arrest is

often refractory to normal resuscitative efforts; prolonged cardiopulmonary support is often required.

## Ultrasound Guidance and Regional Anesthesia

In recent years, ultrasound guidance is being used more commonly for peripheral nerve blocks. Advantages of ultrasound guidance include real-time ability to visualize relevant anatomic structures, needle advancement, as well as the spread of local anesthetic. In addition, ultrasound guidance may reduce the amount of intravascular local anesthetic injected.

Despite clear advantages to the use of ultrasound, it is not a fail-safe mechanism, and potential complications may occur. Zetlaoui et al. reported a case of intravascular injection leading to a seizure, despite negative aspiration during an ultrasound-guided axillary block. The authors conclude that the surrounding veins were probably displaced or compressed by the local anesthetic after initial injections, thereby making their visualization difficult during the final injection. Furthermore, pressure on the ultrasound probe may collapse venous structures and result in negative aspiration of blood. Failure to observe local anesthetic spread on ultrasound imaging may alert the anesthesiologist about an intravascular injection, despite the appearance of a correctly positioned needle around the nerve. A recent study by Fritsch et al. described the occurrence of epidural spread of local anesthetic leading to contralateral blockade after performing unilateral interscalene blocks in cadaveric models with ultrasound guidance. Despite their limited study, the authors conclude that volumes of local anesthetic should be kept as low as possible to avoid epidural spread.

## Prevention and Treatment

Focusing on prevention is of the utmost importance for the anesthesiologist. No single test can guarantee proper needle or catheter placement. Several case reports involving total spinal anesthesia or large bolus intravascular injection have been reported despite use of proper preventive techniques. Possible causes of false-negative aspiration include obstruction of the catheter tip (by tissue or vascular wall), partial dural puncture, or subdural placement. Most false-negative test doses are the result of insufficient wait time or inadequate concentration of epinephrine in solution.

The use of dilute anesthetic solutions and the practice of slow, incremental dosing are both very effective methods of preventing serious complications of local anesthetics. The use of dilute anesthetic solutions for epidurals has been clearly supported in the obstetric literature and is most likely responsible for the sharp decrease in morbidity and mortality associated with epidurals placed on patients in labor. Similarly, the practice of fractional dosing, typically 5 mL, has very effectively

avoided these complications. The ideal incremental dose is one sufficient to elicit mild toxicity symptoms while avoiding the life-threatening sequelae from a large-dose intravascular or intrathecal injection. The addition of epinephrine to local anesthetic provides a means to identify reliably an intravascular injection—namely, if the systolic blood pressure increases by more than 15 mm Hg in healthy patients, such an injection is deemed to have occurred. The efficacy of this method may be less reliable in certain subsets of patients, such as those taking β-blockers and those in active labor.

The American Society of Regional Anesthesia and Pain Medicine recommends taking the following steps to enhance safety:

- Gentle aspiration at the needle or catheter;
- Slow, incremental injection;
- Dose limitation based on established per-kg guidelines (Table 173.1); and
- Use of intravascular markers.

Even with strict adherence to these guidelines, the anesthesia provider should always be prepared to treat the most severe complications of regional anesthesia. The treatment for total spinal block is always supportive and often requires ventilatory assistance with 100% oxygen via mask or endotracheal intubation and circulatory support with intravenous fluids and vasopressors. In the laboring patient, reducing aortocaval compression by positioning the patient in the lateral (tilt) position is necessary.

The treatment for intravascular injection is also mainly supportive, with the use of benzodiazepines, thiopental, or propofol for cessation of seizures and prolonged cardiopulmonary resuscitation for severe cardiotoxicity. Anesthesiologists must remain vigilant for signs of toxicity and must rely on safe practice guidelines to avoid these untoward effects of local anesthetics.

**Table 173.1 ■ Dose Limitation Based on Established per-kg Guidelines**

| Drug | Plain (mg/kg) | With epi (/kg) |
|---|---|---|
| Amides | | |
| Bupivacaine | 2.5 | 3 |
| Dibucaine | 1 | — |
| Etidocaine | 4 | 5 |
| Lidocaine | 4.5 | 7 |
| Mepivacaine | 4.5 | 7 |

| | | |
|---|---|---|
| Prilocaine | 6 | 9 |
| Ropivacaine | 2.5 | 2.5 |
| Esters | | |
| Chloroprocaine | 12 | 15 |
| Cocaine | 3 | — |
| Procaine | 7 | 8 |
| Tetracaine | 1.5 | 2.5 |

## TAKE HOME POINTS

- Know the situations in which total spinal blocks typically occur—in laboring patients, in elderly patients, and so forth.
- Do not do a block without having pharmacologic intervention to treat both CNS and cardiac toxicity immediately available.
- A patient who suddenly starts whispering is deemed to have a high block until proven otherwise.
- Remember that high blocks and intravascular injections can and do occur in patients under general anesthesia—consider this as a possible etiology if the patient suddenly becomes unstable or fails to emerge as expected.

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# Issues Related to Discharging the Postspinal Patient

Christopher E. Howson, MD and Li Meng, MD

You are the attending anesthesiologist at a large academic tertiary care center who is taking over care of a patient for a colleague who is planning to go home for the day. You get report about a 59-year-old Caucasian male with a history of atrial fibrillation who underwent inguinal hernia repair earlier in the afternoon under a spinal anesthetic. Per report from your colleague, both the spinal and the surgery were uncomplicated and the patient's blood pressure, peripheral oxygen saturation, and heart rate were all stable throughout the case. The surgery was about 75 minutes in length and the patient has now been in the postanesthesia care unit (PACU) for approximately 45 minutes; he looks to be stable and is just starting to recover from motor blockade. You gladly agree to assume care of the patient and your colleague goes home.

About 30 minutes later you receive a call from the PACU nurse who is concerned because despite the initial improvement, the patient now seems to be getting weaker during successive motor examinations. You walk to the PACU to assess the patient and find that in addition to near complete motor blockade the patient is also complaining of back pain and pressure near the insertion site of the spinal needle. The patient asks you if "everything is ok." What should you tell him?

## Spinal Anesthesia

The benefits of using a spinal technique include decreased intraoperative blood loss (particularly in orthopedic procedures), lower incidence of postoperative thromboembolic events, lower incidence of postoperative nausea and vomiting, and improvement in pain control. While there are no absolute indications to perform spinal anesthesia, there are an increasing number of clinical situations in which a neuraxial block may be particularly beneficial; these may include patient preference, surgical candidates in which intubation would be high risk, and the planned surgical procedure (i.e., hip replacement). Despite these benefits, there are several preexisting conditions

which may give an intrathecal block a higher relative risk than other anesthetic options; these may include hypovolemic shock (increased risk of hypotension), increased intracranial pressure (risk of brain herniation with loss of CSF), coagulopathy, severe mitral/aortic stenosis, sepsis, and infection overlying the injection site. The careful clinician will weigh the risks and benefits of all anesthetic options, discuss these options with the patient, and make a well-reasoned decision before initiating care.

## Complications

**Backache:** Postoperative back pain is a common complaint among patients undergoing all types of anesthesia techniques, including general anesthesia. Specific to a spinal anesthetic, this pain is most likely related to direct tissue trauma as the needle passes through skin, subcutaneous tissue, muscle, and ligaments although local anesthetic irritation and ligamentous strain secondary to muscle relaxation may also play a role. Postoperative backache is usually mild and self-limited, with most cases resolving within a few days. Treatment options are largely conservative and include acetaminophen, NSAIDs, and warm compresses as needed. It is important to remember that while most complaints of backache are innocuous, they may be a harbinger for more serious complications, such as hematoma or abscess formation.

**Postdural Puncture Headache:** One factor restricting the popularity of spinal anesthesia is the possibility of a postdural puncture headache (PDPH). While the reported incidence of a PDPH varies widely, more recent literature suggests that the actual incidence may be less than 1% if appropriate equipment and technique are used (smaller gauge needle, noncutting tips, bevel parallel to longitudinal axis). Typically, this headache is described as bilateral and extending into the neck; however, the hallmark is that the intensity of pain is positional: worse with sitting or standing and better after lying down flat. While the onset of a PDPH is most commonly within 24 to 72 hours, it is possible that it will occur immediately and will thus be recognized while the patient recovers in the PACU. PDPH usually resolves spontaneously for most patients within a week; however, there are reports of symptoms lasting months to even years. Initial treatment includes conservative measures such as bed rest, hydration, analgesics (acetaminophen or NSAIDs), and caffeine. Despite these therapies the headache may persist and require more invasive treatment such as an autologous epidural blood patch. Success rates approaching 90% for the first blood patch and up to 98% with repeat patches have been documented.

**Table 174.1 ■ Duration of Local Anesthetics Used in Spinal Anesthesia**

| Local Anesthetic | Duration (min) | With 0.2 mg Epinephrine |
|---|---|---|
| Lidocaine 5% | 60–70 | 75–100 |
| Bupivacaine 0.75% | 90–110 | 100–150 |
| Tetracaine 0.5% | 70–90 | 120–180 |
| Mepivacaine 2% | 140–160 | N/A |
| Ropivacaine 0.75% | 140–200 | N/A |
| Levobupivacaine 0.5% | 135–170 | N/A |
| Chloroprocaine 3% | 80–120 | 130–170 |

**Spinal Hematoma:** The development of a spinal hematoma is an extremely rare event (1 in 220,000 spinal anesthetics); however, because of the potentially devastating sequelae, early detection and treatment cannot be overstated. Even a small quantity of blood may compress neural structures and produce ischemia, thus delay of greater than 6 to 8 hours prior to treatment (prompt surgical intervention) reduces the odds of good recovery. Progression of symptoms from back pain or pressure and radicular pain to loss of sensory, motor, and bladder/bowl function should lead to immediate imaging and neurosurgical consultation. Patients currently treated with anticoagulation or antiplatelet therapy, commonly administered to those with atrial fibrillation, hypercoagulable disorders, orthopedic fractures, prior cardiac stenting, and those who are immobile or bedridden are at higher risk for developing CNS hematomas. Understanding the normal duration of action for common local anesthetics in the intrathecal space may raise the index of suspicion for spinal hematoma if a patient's sensory or motor blockade does not improve within a reasonable time period. Table 174.1 lists the duration of action of the more common local anesthetics used for spinal anesthesia, both with and without the addition of epinephrine.

**Transient Neurologic Symptoms:** Although systemic toxicity from local anesthetics is continually a concern for epidural anesthesia, it does not play a large role with spinal anesthetics largely because drug doses are generally considered too low to cause toxic reactions, even if injected intravenously. However, as the number of procedures done under spinal anesthesia increases, there has been growing concern and awareness regarding transient neurologic symptoms (TNS). TNS is characterized by moderate–severe pain radiating down both legs without sensory or motor deficits which occurs after spinal anesthesia. While this complication can occur with all local anesthetics, its risk is considerably higher with use of hyperbaric lidocaine. Other risk factors include lithotomy position, knee flexed position, and outpatient status (early ambulation).

Patients should be counseled that the pain usually resolves spontaneously within 72 hours, although a few case reports indicate that symptoms may take as long as 6 months to resolve.

**High or Total Spinals:** A high or total spinal occurs when excessive amounts of medication are injected intrathecally. The anesthetic spreads to the entire spinal cord and the brain stem, resulting in total sympathetic blockade with subsequent bradycardia, hypotension, and respiratory depression. Respiratory arrest can also occur as the primary and accessory respiratory muscles are paralyzed and the lower-respiratory brain centers are affected. This complication most frequently occurs after attempted epidural anesthesia with inadvertent intrathecal injection. The onset is rapid, usually within 5 to 10 minutes, and can be effectively treated with supportive measures including vasopressors, intravenous fluids, and ventilation.

## Discharge From the PACU

**Criteria Scoring Systems:** Prior to discharge from the PACU, all patients must undergo formal evaluation in order to ensure home-readiness and patient safety. Various scoring systems have been devised in order to guide this process with the common goal of creating a practical, simple, and easy-to-remember protocol that is applicable to all postanesthesia settings. The first and perhaps still most common system is the Aldrete score which originally assessed five parameters: respiration, circulation, consciousness, color, and level of activity (it was later modified to include pulse oximetry). A number of other scoring systems have also been devised in order to improve on the Aldrete score; these include the Post Anesthesia Discharge Scoring System (PADS) and the White Fast-Tracking Score, both designed to facilitate safe and expeditious discharge from PACU. Despite these newer criteria and the known benefits of spinal anesthesia, multiple studies have shown no decrease in PACU time or in the rate of PACU bypass after regional anesthesia. Newer discharge criteria more specific to regional anesthesia, including the WAKE score devised by Williams and colleagues, have attempted to address this finding but have yet to gain widespread use.

**Postspinal Care:** In addition to evaluation with a PACU scoring system as described above, postspinal anesthesia patients should also be assessed for resolution of motor, sympathetic, and sensory blockade. The clinician can test the sacral nerves for perineal sensation, first-toe proprioception, and pedal-plantar flexion to determine regression of the block. For outpatient surgery, the patient should be able to demonstrate a steady gait prior to discharge. In addition, postspinal patients commonly experience urinary retention; however, low-risk patients who received short-acting spinals may be discharged without mandatory voiding. When discharging to an inpatient unit, it is important that floor nursing staff continue frequent neurologic examinations. While

institutional protocols vary, some clinicians may require that the patient be able to bend knees or lift buttocks prior to discharge to inpatient unit.

## TAKE HOME POINTS

- The obligation to guarantee airway control is not obviated by epidural, spinal, or regional techniques.
- Postoperative backache is a common complaint following spinal; symptoms are usually mild and self-limited with most cases resolving within a few days.
- The hallmark symptom of PDPH is that it is positional: worse with sitting or standing and better after lying down flat.
- Progression of symptoms from back pain or pressure and radicular pain to loss of sensory, motor, and bladder/bowl function should raise suspicion of spinal hematoma and lead to immediate imaging and neurosurgical consultation.
- Patients treated with anticoagulation or antiplatelet therapy are at higher risk for developing CNS hematomas.
- While TNS can occur with all local anesthetics, its risk is considerably higher with use of hyperbaric lidocaine.
- Although all surgical facilities should have established PACU discharge requirements, no single standard has been proven more beneficial than others.

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# Epidural or Truncal Block? Sorting It Out

Kareem Aggour, MD

The development of epidural and intrathecal anesthesia has been around almost as long as the discovery of ether by Morton in 1846. In 1898, Bier made history by using cocaine for intrathecal anesthesia. Lumbar epidural anesthesia was described first in 1921 by Fidel Pages. As the development of better techniques and medications were performed, so increased the utilization of epidural analgesia and anesthesia.

Almost all procedures below the head can be performed with neuraxial anesthesia. As more studies were produced, it has been suggested that neuraxial blockade can reduce postoperative morbidity—and possibly mortality. The population in which this has had great impact is in the obstetric patient. Neuraxial blockade allows the mother to remain awake and experience the birth of her child during cesarean sections, as well as providing analgesia during labor and vaginal deliveries.

Epidural analgesia has also been utilized in various thoracic, abdominal, and pelvic procedures to help decrease the surgical stress response to pain. These responses can lead to increased myocardial oxygen demand and decreased oxygen supply, potentially leading to myocardial ischemia. The sympathetic hyperactivity from pain and surgical stress can also have a negative effect on gastrointestinal GI motility as well as adverse endocrine, metabolic, and respiratory effects. Numerous studies have highlighted the protective effects of epidural analgesia compared to systemic analgesia from patient-controlled analgesia (PCA) protocols.

**This does not come without risk.** Procedures involving the neuraxis can come with devastating complications. Generally, epidurals are avoided in anticoagulated patients. With the development of new anticoagulant medications, guidelines are constantly updated on how long a patient needs to discontinue the particular medication to reduce the risk of an epidural hematoma. Timing of resumption of these medications can pose a challenge as well. Some of the other contraindications to epidurals include local infection, certain spine surgeries, and patient refusal to name a few. An epidural may need to be avoided in patients who are hemodynamically unstable or with surgeries involving massive blood loss and possible coagulopathy.

A patient that either refuses or cannot have an epidural will still need some manner

of perioperative pain control. This is commonly done with pharmacologic modalities. Opioids are very commonly used in the perioperative period. The therapeutic index can be narrow in certain patient populations. Overmedication can lead to respiratory depression, constipation, and physical dependence. Epidurals have helped to reduce the amount of opioids required perioperatively, helping to decrease these unwanted effects.

But is there an alternative to decrease opioid consumption in a patient that cannot have an epidural? Truncal blocks include newer regional anesthesia techniques that provide analgesia after thoracic, abdominal, and pelvic surgeries.

Paravertebral blocks have been used as an alternative, providing near-equivalent pain relief as epidural analgesia in thoracic surgeries where an epidural may not be needed or is too risky. Coagulopathies and anticoagulation therapy are more of a relative contraindication and there is a better side effect profile and overall lower complication rate than epidurals, especially when used with ultrasound guidance. It involves injection of local anesthetic (LA) adjacent to the thoracic vertebrae close to where the spinal nerves emerge from the intervertebral foramina. The paravertebral space is a wedge-shaped space that is bordered by the pleura, the vertebral body, and the costotransverse ligament. The local anesthetic can spread to levels above and below, and involve the intercostal nerves, sympathetic chain, and varying degrees of epidural spread.

The transversus abdominis plane (TAP) block was first described as a landmark technique in 2001 by Rafi and involves injection of a local anesthetic through the lumbar triangle into the TAP between the internal oblique and the transversus abdominis muscles targeting the nerves of the anterolateral abdominal wall. It is most successful in treating somatic pain. Dye studies have found that the levels most commonly involved are T10–L1. Subcostal TAP blocks or rectus sheath blocks have been described to provide analgesia for incisions above the umbilicus (T7–T9).

A newer technique, the quadratus lumborum (QL) block, has been recently described to be able to cover a wider distribution of dermatomes—some of the contrast studies quote T6–L1. The evidence is still limited but seems to have very positive potential benefits. It involves placing the ultrasound probe more posterior-lateral to the TAP view, following the TA muscle as it becomes aponeurotic, and then visualizing the QL muscle come into view. The local anesthetic spreads along the ventral side of the QL muscle toward the paravertebral space. Thus, it may be an indirect paravertebral block, achieving greater dermatomal spread than a TAP block.

Pecs blocks have been described as an interfascial plane block to provide analgesia to the upper anterior chest wall. It has had good utility in breast surgeries. It involves injecting local anesthetic into the plane between the pectoralis major and minor muscles. For procedures extending further into the axilla, the pecs 2 block involves

injection of LA more laterally between the pectoralis minor and serratus anterior muscles.

Ilioinguinal and iliohypogastric blocks can be utilized for procedures involving the lower abdomen to the pubic region. The ilioinguinal nerve innervates the upper medial part of the thigh and upper part of the genitalia. The iliohypogastric nerve provides sensory innervation of the buttock and the abdominal wall above the pubis.

Intercostal nerve blocks provide selective analgesia based on which levels are injected. The three intercostal muscles are visualized using ultrasound and the local anesthetic is injected between the internal and innermost intercostal muscles.

Here is the way I approach perioperative pain control in patients. First, of course, I see what type of surgery they are having. With large incisions involving the thoracic region, abdomen, or pelvis, I start to consider epidural placement. I then do a detailed chart review of the patient paying close attention to pertinent labs, any anticoagulation the patient may be receiving, or ongoing coagulopathies. I then try to have an idea of how much potential blood loss or hemodynamic variability there may be. A patient who has cardiovascular or cerebral dysfunction may not tolerate the hypotension that may come with an epidural. Also, if there is the potential for significant blood loss and/or postoperative coagulopathy, like during a hepatectomy, an epidural may need to be considered cautiously. I like to have a conversation with the surgeon beforehand to review these details and decide whether an epidural would be a good option to present to the patient. Other things to consider are if the patient suffers from chronic pain and takes large amounts of opioids at home. Their response to opioids will be less effective than in an opioid naïve individual, another important consideration in the postoperative period. They would probably be good candidates for an epidural or a truncal block. For surgeries with smaller incisions, outpatient procedures, or short hospital stays, a single shot truncal block may be considered so as not to delay discharge or expose the patient to the risks of neuraxial blocks when it is not necessary.

When I consent patients for epidural catheters, I make sure they understand the steps involved in the procedure. It is important to know if the patient is able to sit up for placement, or will have to lie in a lateral position. I explain to them the risks/benefits of an epidural catheter and answer any questions or concerns they may have. I let them know that serious risks such as bleeding, infection, and nerve injury are extremely rare. I also have the discussion about possible postdural puncture headache and what to expect if it occurs (postural headache, possible need for blood patch). If the patient agrees, then we proceed. It is important for them to understand that epidurals have advantages of reducing opioid consumption, which reduces the risk of postoperative bowel dysfunction. It also reduces pulmonary atelectasis from splinting, and will make the patient overall more comfortable compared to parenteral opioids alone.

What if a patient is not a good candidate for an epidural or refuses one? What are our other options? If regional analgesia is still being considered, there are various other options that were described above. If a patient is having a thoracic procedure done, a paravertebral block may be considered. You may still see some of the hemodynamic changes from an epidural but that would depend on the volume and potency of the local anesthetic used. Surgery involving the upper abdomen? A paravertebral, QL, subcostal TAP, or rectus sheath block may be considered. Lower abdomen or pelvis? Consider a traditional TAP block, or ilioinguinal/iliohypogastric block.

With most truncal blocks, I will usually consent the patient to have them done postoperatively. I sometimes place truncal catheters under general anesthesia while the patient is still in the operating room. These are usually reserved for larger incisions, prolonged hospital stay, or patients who may not tolerate pain as well or will have difficulty tolerating the block in PACU. If a patient is unsure about an epidural or a truncal block, I usually describe both procedures to them and explain to them that an epidural will likely provide superior pain control with a more complete dermatomal coverage. The important thing is to do what is safest for the patient while trying to provide the best option for perioperative pain control.

## TAKE HOME POINTS

- Epidural analgesia is the most effective method to anesthetize a large dermatomal distribution. Downsides are hypotension, lower-extremity weakness, urinary retention, and risk of hematoma if coagulopathic.
- Paravertebral blocks are near equivalent to epidurals in providing analgesia but will need bilateral injections if incision crosses midline and may still have some epidural spread leading to side effects.
- TAP, subcostal TAP, rectus sheath, and QL blocks are great for abdominal surgeries. Downside is limited dermatomal spread necessitating multiple injections.
- Pecs blocks are newer techniques that have the greatest utility in breast surgeries so far.
- Intercostal, ilioinguinal/iliohypogastric blocks are more selective blocks that are limited to smaller regions but may have utility if access to the site of TAP, PVB is limited.

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# Dang It! Wet Tap

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A postdural puncture headache (PDPH) is a headache that occurs as a result of cerebrospinal fluid (CSF) leakage though a hole in the dura mater of the meninges. This hole is often created by accident when, while placing an epidural, a medical provider advances the needle a few millimeters too far and CSF pours out. A PDPH can also occur after using a spinal needle, though the use of a smaller needle usually causes a less severe headache that is of shorter duration. PDPH is defined by the International Headache Society as a "headache occurring within 5 days of a lumbar puncture, caused by cerebrospinal fluid (CSF) leakage through the dural puncture." It is usually postural, that is, it worsens upon standing or sitting and improves upon lying in a horizontal position. PDPHs are sometimes associated with nausea, tinnitus, hearing loss, vertigo, and rarely with double vision. The International Headache Society states that the headache "remits spontaneously within 2 weeks, or after sealing of the leak with autologous [blood]." It should be noted that not all PDPHs resolve within 2 weeks and they can be associated with permanent long-term morbidity.

## The Differential Diagnosis: Is This a PDPH?

**Not all headaches after a dural puncture are a PDPH!** There are rare and serious causes of peripartum headache that must be ruled out (e.g., venous sinus thrombosis, meningitis, subdural hematomas) as well as more common headaches (e.g., tension, migraine, and cluster headaches). Tension headaches are very common and in our experience are the cause of most of the headaches that occur in the first postpartum week. They last anywhere from 30 minutes to 1 week and are often associated with the stress of laboring and the strain involved with delivering a baby. Patients with tension headaches often complain of neck and posterior head tightness, the headache is not affected by activity, and they almost always can still take care of their baby. We have found that cyclobenzaprine and nonsteroidal anti-inflammatory drugs are quite helpful in treating tension headaches. Another common peripartum headache is the migraine headache. Postpartum migraines occur in up to half of all women with a history of

migraine headaches. They are triggered by declining estrogen levels after delivery. They typically last less than 3 days, are made worse by activity, and as we all know from classic medical teaching can be associated with auras. The aspirin, tylenol, caffeine combination drug (i.e., Excedrin) is quite effective at treating migraine headaches, as are triptans.

When a patient has a postural headache after a dural puncture we believe the real differential is quite simpler: a PDPH or pneumocephalus. A patient can get pneumocephalus if loss of resistance is attempted with air and upon puncturing the dural air is injected into the intrathecal space. The air can irritate the meninges resulting in head pain that can be associated with tinnitus, nausea, and vomiting, just like a PDPH. If you are truly concerned that a patient may have pneumocephalus a CT scan must be ordered to confirm the diagnosis. Luckily, the air is usually resorbed within 5 days and patients often have no long-term sequela.

## Why Is a "Simple Headache" so Important?

Unintentional dural puncture in the obstetric patient is a complication. In an obstetric anesthesia review of the American Society of Anesthesiologists Closed Claims Database, PDPH was the third most common reason for claim after newborn death/brain damage and maternal nerve injury. While the percentage of claims for maternal death and newborn death/brain damage has decreased over the past few decades, the percentage of claims for maternal headache has remained steady. Thus, the PDPH is a problem that does not seem to be going away.

Furthermore, dural punctures are not just associated with a headache. There are case reports of cranial nerve palsies involving cranial nerves 3 through 8. Cranial nerve 6, the abducens nerve which pulls the eye laterally, is most susceptible to damage due to its long path from the brainstem to the eye. Injury to the abducens nerve results in unopposed medial pull on the eye and sometimes double vision. Subdural hematomas have also been described from loss of CSF resulting in a caudal pull on the brain and tearing of the bridging subdural veins. Dural venous thrombosis has been described, perhaps due to a compensatory venous dilation after intracranial pressure decreases from CSF loss. Lastly, seizures and the development of chronic migraine headaches has been described. It is thought that dural puncture could incite cerebrovascular vasodilation and thereafter the brain may retain a memory of the event, such that smells, stress, and hormone changes could trigger future migraine headaches.

Most PDPHs do resolve within 1 week; however, some last a very long time. Although it is a very old article, Vandam et al. described over 1,000 patients with PDPH and found that over one out of four patients had a headache that lasted longer than 1 week. In another retrospective study, MacArthur et al. found evidence of PDPHs

lasting over 8 years. There is even a case report of a PDPH lasting over a year and finally being treated permanently with an epidural blood patch!

## What Causes This Type of Headache?

Two proposed pathophysiologic mechanisms for PDPH are (a) leak of cerebrospinal fluid (CSF) leading to loss of brain support, caudal displacement of the brain and traction on the meninges, which hurts, just think of meningitis; and (b) loss of CSF resulting in decreased intracranial CSF volume, causing a compensatory cerebral vasodilatation, which is a well-studied way to get a headache, just think of migraine headaches. Personally, we feel that there is more evidence for the cerebral vasodilation theory as not all patients with a PDPH have evidence of caudal brain displacement and not all patient with a PDPH have decreased CSF pressure. Furthermore, in a novel study published looking at cerebral blood flow characteristics after lumbar puncture, it was found that middle cerebral artery velocity significantly decreased (indicating cerebral vasodilation) only in patients that developed a PDPH and not in patients that were headache free.

## I Caused a Dural Puncture—Now Who's Going to Get a Headache?

Significant risk factors for PDPH after dural puncture include lower age, female gender, larger needle diameter, cutting needle-tip design, a history of a previous PDPH, smaller BMI, and a history of multiple attempts to achieve puncture. Younger patients are more prone to PDPH, perhaps, because as patients get older their dura is more calcified and inelastic. Premenopausal women are twice as likely as men to get a PDPH. This risk parallels what is known about migraine headaches as women are more likely to have migraine headaches than men. It is thought that the cerebral blood vessels in women may be more responsive to external triggers such as drops in CSF pressure or hormone concentration changes. The risk for PDPH relates directly to the diameter of the needle used, with larger needles causing larger outflow of CSF, and consequently a higher risk of PDPH. Needle-tip design is also important. Pencil-point needles (Sprotte, Whitacre) have a side orifice on the needle and result in a lower incidence of PDPH than do those with a cutting-point (Quincke). Thin patients are more likely to get a PDPH than obese patients. The reason is controversial, but it may have to do with potentially increased intraabdominal pressure in obese patients which may act to decrease CSF outflow. Lastly, the more holes one puts in the dura, the more likely CSF outflow is to overcome the rate of CSF production, resulting in a PDPH. Consequently, as the number of attempts at block placement and/or dural punctures increases so does the risk of PDPH.

## What Do I Do After an Unintentional Dural Puncture?

Most anesthesiologists recommend removing the needle and placing the epidural in a new interspace, usually above the previous attempt. We recommend going above the previous attempt as the catheter will usually thread up when the bevel is directed cephalad. This way the catheter would not be threaded past the dural hole that was previously created.

Some anesthesiologists recommend placing an intrathecal catheter and using this for obstetric labor analgesia and when necessary, anesthesia for cesarean section. This technique has become popular as there is some evidence that a spinal catheter left in place for 24 hours can decrease the incidence of PDPH after dural puncture. The theory is that the catheter initially provides a mechanical obstruction to prevent CSF outflow and over time causes inflammation which helps promote dural closure. Personally, we are cautious using this approach as a sleepy provider that is asked to bolus a catheter in the middle of the night could very easily bolus a spinal catheter with an epidural dose resulting in a potentially life-threatening situation.

## Oh No! This Is a PDPH. What Do I Do NOW?

Anesthesiologists are a creative species. Our community has come up with a number of potential treatments for the PDPH. Among these are a technique where you block the sphenopalatine ganglion with lidocaine placed through the nose, occipital nerve blocks in the back of the head, bed rest, all sorts of pain medicine from narcotics to antiepileptics, abdominal binders, intravenous hydration, oral hydration, DDAVP, ACTH, hydrocortisone, triptans, theophylline, epidural saline injections, epidural saline infusions, epidural injection of dextran, and caffeine. While there are many options to choose from, there is unfortunately not much evidence of long-term efficacy for any of these techniques. Yes, they can often decrease pain scores immediately after intervention, but they do not; in general, change the long-term prognosis of a PDPH or decrease the need for an eventual epidural blood patch.

Caffeine deserves special attention as it has become almost synonymous with PDPH treatment. However, surprisingly there is little evidence of efficacy. There is only one published randomized controlled trial examining the effectiveness of caffeine as a treatment for PDPH. This article published in 1990, randomized 40 women with a diagnosed PDPH to either 300 mg of oral caffeine or placebo. While pain scores were lower 4 hours after intervention in the caffeine group, there was no statistically significant difference in pain scores 24 hours after intervention. The authors concluded that caffeine can provide temporary, but not long lasting benefit. Caffeine is also a potent central nervous system stimulant and there are case reports of seizures after caffeine, so it is not without risk. The point may, however, now be mute as intravenous

caffeine is no longer commercially available in the United States.

The epidural blood patch is the only intervention that has shown consistent effectiveness in not only providing immediate relief of symptoms, but also affecting PDPH disease progression. It should be noted that a previous epidural blood patch is not a contraindication to future epidural anesthesia and human immunodeficiency virus infection is not a contraindication to doing an epidural blood patch. The epidural blood patch has two effects: the early effect is to compress the dura, restoring CSF pressure and relieving the headache; the late effect is to seal the dura and prevent the future development of a headache. Multiple studies have shown the effectiveness of the epidural blood patch in relieving symptoms of PDPH, but unfortunately, the success of the epidural blood patch appears to be lower in the obstetric population than the general population.

In addition, as with any procedure, an epidural blood patch has its own set of complications, the most common of which is back pain or pressure. **This pain/pressure can be worse than the initial headache for some women so we commonly ask women if they are able to care for their baby. This question helps to triage who may most benefit from the blood patch. Women that are so debilitated that they cannot care for their baby will usually trade some back pressure for headache relief.** Conversely, we have had women with less severe headaches get upset after getting a blood patch because the resultant back pressure was worse than their initial headache. It should be noted that anecdotally speaking, less severe headaches usually last a shorter period of time. For such patients, it can be reasonable to try conservative measures to mask the pain while the body attempts to heal itself.

## How Do You Perform an Epidural Blood Patch?

An epidural blood patch is a procedure in which sterile blood is injected into the epidural space near the area of a previous dural puncture. In general, we try to insert the blood one level below the level of the previous dural puncture as we know that blood will preferentially spread cephalad, perhaps because the bevel of the needle points in that direction and because there is less pressure in the epidural space cephalad, due to negative intrathoracic pressure. An epidural blood patch requires two people to complete. One person sits in front of the patient and with a sterile prep and drape and sterile needle obtains venous blood. This blood is then handed to the other provider sitting behind the patient who has just obtained access to the epidural space. Give some thought as to whether you want the person you got the wet tap while attempting an epidural placement to recuse himself from the blood patch. Sometimes, it is a bit better psychologically for the patient not to have the anesthesiologist who missed the epidural present themselves for a second attempt.

Blood can usually be injected more quickly up to a total of 15 mL. At this point, the injection speed should be slowed and the patient should be told to tell you if they get any new neurologic symptoms (paresthesias, weakness, etc.) or if the pressure in their back gets to be too much. Often one will be able to inject over 20 mL of blood. If the patient never tells you to stop, it is ok to continue to inject blood up to a total of 30 mL. After the injection of blood, the epidural needle can be removed. The patient should be kept in the hospital for 1 to 2 hours postprocedure in a recumbent position before discharge home. Any new neurologic symptoms should prompt a longer stay and consultation with the neurology folks.

## TAKE HOME POINTS

- A PDPH is a postural headache, often associated with nausea, tinnitus, hearing changes, or vertigo, that occurs after a known or suspected hole is created in the dura.
- The differential diagnosis for a peripartum headache includes serious complications such as venous sinus thrombosis, meningitis, and subdural hematomas, as well as more common causes like tension, migraine, and postdural puncture headaches.
- PDPHs are **not** always self-limited and "just a headache." They can last a long time, be quite debilitating, and cause permanent and serious morbidity.
- The PDPH is probably caused by loss of CSF resulting in decreased intracranial CSF volume, which causes a compensatory cerebral vasodilatation.
- Risk factors for the development of a PDPH after dural puncture include the following: younger age, female gender, larger needle diameter, cutting-tip needle design, a history of previous PDPH, smaller BMI, and a history of multiple needling attempts.
- There are numerous published ways to treat a PDPH; unfortunately, most, including caffeine, have very little evidence of effectiveness. The epidural blood patch is the only intervention that both provides immediate symptom relief and affects PDPH prognosis.
- When performing an epidural blood patch slow down your rate of injection after 15 mL of blood has been given as large volumes of blood injected quickly can result in new neurologic symptoms and/or severe back and leg pain.

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# Consider Continuous Paravertebral Block as Your Primary Analgesic Technique

Bruce Ben-David, MD and Brian T. Gierl, MD

Your colleagues who are surgeons and your hospital administration are increasingly pushing the limits on what can be done as an ambulatory surgical procedure. Plans are now taking shape to perform mastectomies as same-day surgery. You are asked for your input into realizing this goal.

## Considerations

Although many anesthetics are associated with rapid recovery, pain and postoperative nausea and vomiting (PONV) can stop same-day discharge. These problems are not unrelated. Postoperative pain can itself lead to PONV, and so can its treatment with opiates. In fact, we now know that opiate side effects are linearly correlated with opiate consumption. Since a mastectomy is a very painful procedure, patients will need significant opiate analgesics postoperatively; unless a regional technique is used.

Opiates alone may be insufficient to get patients mobilized and discharged home. Mu-agonist-receptors have limited participation in the relevant pathways, so they are less effective in controlling pain with movement than pain at rest. Moreover, severe postoperative pain correlates with the development of persistent or chronic postoperative pain. This is a serious concern in mastectomy surgery; a high percentage of patients having mastectomy develop chronic pain known as "postmastectomy syndrome." There is evidence that a perioperative neural blockade may reduce the occurrence of persistent postoperative pain. Neural blockade should, therefore be considered a critical component of a multimodal analgesia regimen—one that is begun in the surgery center and continued at home. It is a suggested element of the recently published multisociety postoperative pain guidelines that are suggestions to minimize postoperative pain while reducing opiate usage in the face of the current opiate crisis in the United States.

Lastly, some studies suggest that neural blockade, presumably by preventing the

neurohumoral stress response and by decreasing the use of opiates (both of which may increase cancer cell growth and invasiveness while suppressing the immune system's ability to eliminate residual disease) may improve long-term oncologic outcome. In total, these considerations make a compelling case to include neural blockade as part of the standard care of these patients.

## Options

So where is the best place to put the local anesthetic? Multiple intercostal blocks or local-anesthetic wound infiltration provides analgesia, but its duration is limited and pain returns too soon. A "soaker" catheter infusing local anesthetic into the wound may add modestly to the analgesia, but the technique generally has not been shown to provide the same level of analgesia as do neural-blockade techniques.

The most commonly used neural-blockade technique today for procedures of the thorax and abdomen is thoracic epidural analgesia (TEA). While TEA can be expected to provide analgesia far superior to that possible with patient-controlled analgesia (PCA) opiate, it is not a practicable solution here. TEA use is associated with several side effects, some of them quite common, which render the technique unacceptable for the ambulatory surgical patient. These side effects include pruritis, urinary retention, nausea and vomiting, respiratory depression, and hypotension. Walking with a TEA can lead to falls and limits postoperative ambulation, making it a nonideal choice. Though probably not relevant here, TEA use is a particular concern in the patient who will be administered anticoagulants postoperatively. **In the United States, epidural hematoma has rendered dozens of patients paraplegic when, postoperatively, low-molecular-weight heparin was administered in conjunction with the use of epidural analgesia.**

An alternative technique of neural blockade, continuous paravertebral block (CPVB), is nearly devoid of TEA's side effects and is at least as effective an analgesic as TEA because higher levels of local anesthetic can be used safely in the nonneuraxial paravertebral space. Originally described more than 100 years ago, paravertebral block has found renewed popularity in recent years and has proven extremely useful as a continuous technique with the use of modern catheters. Its advantages include its ability to achieve a high degree of sensory and analgesic blockade without causing urinary retention, respiratory depression, pruritis, or hypotension. CPVB has shown benefits for many other patients; for example, CPVB better preserves forced vital capacity (FVC) following thoracotomy. It also has been shown to benefit patients after rib fractures. It preserves lower-limb strength, thus facilitating early mobilization of patients. It affords the possibility of unilateral or bilateral blockade, as needed. Lastly, its offset from the midline promises less risk of spinal cord injury due to direct needle trauma or hematoma. The CPVB is typically placed just lateral to the midline but the lateral

intercostal approach is feasible in situations of coagulopathy, spine abnormality, or spinal trauma.

## Anatomy of the Paravertebral Space

The thoracic paravertebral space is a triangular space bounded anteriorly by the parietal pleura, posteriorly by the superior costotransverse ligament, and medially by the vertebral body, intervertebral disc, and intervertebral neural foramen. The apex of the triangle laterally is continuous with the intercostal space. The space is bisected by the very thin endothoracic fascia, which effectively creates two "compartments." The anterior compartment contains the sympathetic chain, and the posterior compartment contains the intercostal nerve, dorsal ramus, intercostal blood vessels, and rami communicants. Spinal nerves in the paravertebral space are relatively devoid of fascial covering, making them uniquely and exceptionally sensitive to local anesthetic blockade. The paravertebral space openly communicates cephalocaudad, thereby making it possible to effect multiple-dermatomal blockade via a single catheter positioned in the space.

## Technique of CPBV

Placing the continuous paravertebral catheter preoperatively is recommended, because it is technically easier, it affords the chance to use the block as part of the anesthetic, and it allows recovery room nurses immediate access for postoperative pain control. The patient is positioned sitting, with feet dangling over the side of the bed. An intravenous infusion is established, standard monitors applied, and mild sedation administered. The relevant spinal process is identified (note that the steep angulation of thoracic spinous processes brings them opposite the transverse processes of the adjacent more caudad vertebra) and the needle-entry point is marked 2.5 cm lateral to the spinous process. Catheter placement should be at a dermatomal level that represents the midpoint of the surgical wound. Patients may exhibit a vagal response during performance of the block. A prepared syringe of an anticholinergic drug (e.g., glycopyrrolate) and a syringe with a pressor agent (e.g., ephedrine) therefore should be immediately at hand.

The skin is disinfected and local anesthesia is injected subcutaneously at the needle-entry point. A 9-cm 18G Tuohy needle with 1-cm graduated markings is introduced and walked caudally off the transverse process to a depth 1 cm beyond the transverse process. Often one feels a confirmatory "pop" upon penetration of the costotransverse ligament. A drop of fluid is placed in the needle hub, and the patient asked to inspire deeply. Correct placement is confirmed by lack of movement of the fluid bubble. A drawing inward of the fluid indicates intrapleural needle placement, in which case the

needle should be immediately withdrawn. After negative aspiration for blood, 5 mL of 0.5% ropivacaine is injected. Having an assistant inject through an extension tube is helpful, as this helps avoid significant movement of the needle. Following the injection, the extension tube is disconnected and a polyamide, 20G, closed-tip, multiport catheter is inserted to a depth of 3 to 5 cm beyond the tip of the needle. The catheter is affixed in standard fashion.

Several techniques of ultrasound-guided thoracic PVB have been described. Though some authors have suggested US-guided PVB to be superior to a landmark-guided approach direct evidence of this is lacking. Those techniques that use a medial angulation of the needle toward the neuraxis do seem to have a higher incidence of epidural spread of the local anesthetic as opposed to techniques using a cephalo-caudad angulation of the needle in a parasagittal plane. Hydrolocation using repeated small injections of saline aids in visualization of the needle tip as well as in the confirmation of proper needle position by anterior displacement of the pleura.

Postoperatively, a pump containing 0.2% ropivacaine is attached to the CPVB catheter and is infused at a rate of between 6 and 10 mL/hr. A disposable infusion pump can be used for this purpose just as for other continuous peripheral-nerve blocks in patients having ambulatory surgery. Before discharge, patients should receive a set of written instructions and a phone number to call with questions or concerns. Catheters can be easily removed by the patients themselves at home and may be discarded along with the disposable pumps.

## Multimodal Analgesia: Making the Most of Your Nerve Block

CPVB and all other nerve blocks, for that matter, are only a temporary and a very incomplete treatment of postoperative pain. Even complete neural blockade does not inhibit the accumulation of inflammatory mediators in the peripheral tissues and their influence on nociceptors. Nor will it block the access of inflammatory mediators to the central nervous system where nociceptive processing will be altered as well. Therefore, once the neural blockade is lifted, the patient is still left in a hyperalgesic state. In this sense, neural blockade can be viewed as simply a window of opportunity. It allows a several-day window during which to mobilize the patient rapidly, control her pain effectively, and minimize opiate consumption. But neural blockade can provide only a partial answer to postoperative pain.

By combining the nerve block with other analgesic agents, one can achieve better short-term and long-term pain relief. These agents include acetaminophen, nonsteroidal anti-inflammatory drugs, COX-2 antagonists, gabapentinoids, N-methyl-D-aspartase (NMDA) blockade (e.g., intraoperative low-dose ketamine, dextromethorphan,

magnesium), single-dose dexamethasone, α-2 agonists (clonidine, dexmedetomidine), and, of course, short-acting opioids for breakthrough pain. Use of multimodal analgesia not only enhances the success of early analgesia and discharge of patients but also reduces patients' chances of developing a chronic pain state.

## TAKE HOME POINTS

- CPVB is a remarkably effective analgesic technique, with many advantages over TEA.
- For bilateral breast surgery, as for surgery of the abdomen or retroperitoneum, one needs to place bilateral CPVB catheters.
- Heavy reliance on opioid analgesia is contrary to many of our modern goals of postoperative care, as described by Chou et al.
- Do not rely solely on neural blockade for postoperative analgesia. The best results, in the short and long terms, are achieved by using a multimodal approach.

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# Pneumothorax After Paravertebral, Supraclavicular, or Interscalene Block

Nathalie Lunden, MD

Regional anesthesia can be an invaluable technique leading to improved analgesia, reductions in opioid requirements, and enhanced recovery after certain procedures. However, every regional technique is associated with its own set of risks. There are several blocks which have been associated with a risk of pneumothorax (PTX); therefore, it is important to discuss prevention, diagnosis, and management.

## Avoiding Iatrogenic Pneumothorax

There are several blocks that have a risk of PTX including interscalene, supraclavicular, infraclavicular, intercostal, and paravertebral blocks. There are also blocks of the chest wall that have more recently been described (i.e., PECS and serratus anterior plane block) that have a risk of PTX given their close proximity to the pleural cavity. Supraclavicular and paravertebral blocks have been reported to have relatively high rates of PTX and will be the focus of this chapter. Yet it is important to note that the use of ultrasound may have reduced these rates significantly.

The divisions of the brachial plexus in the supraclavicular region are intimately related to the dome of the lung. The nerves travel anteriorly to the dome and the first rib. Based on the anatomy, it is easy to understand why PTX is a risk with this block. Fortunately, there are techniques that can be employed in order to minimize this risk. Firstly, the use of ultrasound should be considered since the incidence has been demonstrated to be reduced with this modality. When the probe is situated in the supraclavicular fossa, the axillary artery and brachial plexus can be seen directly above the first rib and pleura. The first rib can be identified by its hyperechoic surface and dark shadow underneath. The lung is characterized as having a hyperechoic surface as well, but has a grainy image below (due the specular properties of the lung). The probe is translated/rotated until the first rib is seen beneath the target injection site. This provides a “backstop” between the needle and the lung if the needle were to be advanced inadvertently. It is also important to note that the structures can be very

superficial, thus the needle should be visualized in-plane at all times.

The thoracic paravertebral space is a wedge-shaped space on either side of the vertebral column. The parietal pleura forms the anterolateral boundary. There are multiple accepted techniques to perform this block. Intimate knowledge of the anatomy is important for avoiding complication. As you trace the pleural cavity posteriorly from lateral to medial, the pleura dives anteriorly in relation to the paravertebral space. In other words, the parietal pleura moves from superficial to deep the more medial you go along the transverse process. Therefore, avoiding an excessively lateral needle position can reduce risk of PTX and potentially increase block success. For example, when imaging the spine in the sagittal plane, getting a most medially positioned view of the transverse processes or slight medial tilt can avoid a lateral puncture if you continuously visualize your needle in an in-plane approach. A word of caution—medial approaches may increase the risk of epidural injection. Care should be taken with sedation to achieve a comfortable yet directable patient to avoid unexpected movements.

## Diagnosing Pneumothorax

Depending on the severity, signs of PTX can range from very subtle to obvious. **Symptoms are not always immediate and may even take up to 24 hours to diagnose**. When the pleura is punctured, there can be a sudden onset of chest pain, dyspnea, cough, and rarely hemoptysis. On physical examination, you may appreciate hyperresonance, decreased excursion on the affected side, and/or decreased breath sounds. More worrisome signs include hypoxia, tachycardia, and hypotension.

Diagnosis is usually confirmed with imaging. The radiograph of choice is an X-ray in the upright position since supine films are notoriously inaccurate. A CT scan is more sensitive than a chest radiograph for small pneumothoraces and is currently the gold standard. However, one may argue the feasibility of a CT scan especially in a rapidly decompensating patient. Ultrasound diagnosis has a high sensitivity and specificity in trained hands. It can be a quick, low cost, and accurate alternative given the ease of detection and availability in most anesthesia practices. Ultrasound diagnosis can be easily done with the patient supine looking for lung sliding, B-lines, and sea-shore sign with M-mode (all of which are absent in a PTX).

## Treatment

Treatment of a pneumothorax is based on severity. If the PTX is small and the patient is stable, conservative management like rest, supplemental oxygen, and observation may be all that is necessary. However, even a small PTX can progress in severity, so close monitoring and follow-up is necessary. In severe cases where hemodynamic instability

and respiratory deterioration are present, emergency needle decompression may be warranted and/or subsequent chest drainage. In any case, surgical consultation is advisable to aid in severity assessment and treatment.

## TAKE HOME POINTS

- Techniques to avoid a PTX during a supraclavicular block include using ultrasound, continuously visualizing the needle in-plane, identifying the first rib and using it as a "backstop."
- Keeping a more medial approach to paravertebral block may reduce the risk of pleural puncture, but avoid being so medial that you enter the epidural space.
- Consider ultrasound for diagnosis of PTX, it is highly sensitive/specific, low cost, and easy to learn.
- Treatment is based on severity and does not always require invasive intervention. Consider surgical consultation.

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# Epidural Anesthesia for Mastectomy

Jennifer Vookles, MD MA

Mastectomies are commonly performed under general anesthesia; however, a variety of regional anesthetic techniques for breast surgery have been evaluated as either the primary anesthetic, adjunctive anesthesia, and/or postoperative analgesia. Examples of these techniques include field local infiltration, brachial plexus blocks, paravertebral blocks, intercostal nerve blocks, and thoracic epidural anesthesia.

These different approaches have a wide range of utility. At one extreme, local infiltration is very limited and could only be used as the sole anesthetic choice for more confined surgeries. Also, the benefits of local anesthesia as well as some of the peripheral nerve blocks cannot be extended beyond the duration of the local anesthetic effect. At the other extreme, thoracic epidural analgesia (TEA) can be used as the sole anesthetic for extensive breast procedures and provide prolonged postoperative pain control via continuous infusion. By avoiding volatile anesthetics and opioid analgesics, less postoperative nausea and vomiting and shorter recovery times have been reported. Even if the TEA is used as an adjunct to a general anesthetic, there can be substantial benefits. TEA including use of a local anesthetic will selectively block cardiac sympathetic fibers resulting in greater hemodynamic stability, improved myocardial oxygen balance, and an attenuated stress response. Preemptive analgesia may also play a role in decreasing postoperative pain and opioid requirements. Greater patient satisfaction has been reported.

Yeh and Doss both utilized TEA for their primary anesthetic plus sedation. They placed catheters at a T5–6 or T6–7 level and threaded catheters 3 to 5 cm into the epidural space. One reports maintaining a block between C5 and T6 with 2% lidocaine, the other from roughly 2 cm below the clavicle and to the costal arch inferiorly with 0.2% ropivacaine. Both approaches were successful although in some patients the surgeons did need to supplement with local anesthetic during the axillary node dissection.

Postoperative analgesia can also be maintained by a variety of epidural infusions. Doss recommends infusing 0.2% ropivacaine beginning at 4 to 6 mL/hr. Systemic opioids may be needed if the patient experiences inadequate analgesia. At my

institution, an infusion containing a lower concentration of local anesthetic in combination with a low opioid dose is more commonly utilized (usually 0.1% ropivacaine, hydromorphone 10 µg/mL); our initial infusion rate is 10 mL/hr, but this can titrate as indicated by either pain or side effects.

Either technique can be effective, but each has unique precautions. With higher local anesthetic doses, upper-extremity weakness and subjective shortness of breath should be monitored. The latter is generally due to chest wall numbness, and patients generally tolerate this well with education. Diaphragmatic weakness would not be expected in the absence of proximal upper-extremity weakness. Weakness is less common using lower concentrations of local anesthetic; however, these patients will usually require some opioid for adequate analgesia. The opioid can be provided as part of the epidural infusion as is done at my institution, or systemically. The usual potential opioid side effects can occur with either approach.

## TAKE HOME POINTS

- Epidural anesthesia is a well-described and efficacious technique for mastectomy patients.
- Greater patient satisfaction has been reported.
- A variety of strategies for catheter management and dosing will give satisfactory results. Also, if using the epidural as your primary anesthetic, expect and/or request that the surgeons supplement with local anesthesia for axillary node dissection.
- This author uses a low-dose local anesthetic/low-dose opioid infusion for postoperative analgesia.

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# What Is the Right Level for Postoperative Epidural Catheter Insertions Based on Type of Surgery?

Joelle Karlik, MD and Andrew Neice, MD

You are taking care of a 72-year-old female who is presenting for a left open nephrectomy. You plan on placing an epidural catheter for postoperative analgesia. The patient refuses a preoperative epidural but postoperatively is in severe pain and requests epidural placement. At what level should you place the epidural? Does placement differ from a preoperative epidural?

## Location, Location, Location

Precise and thoughtful placement of epidural catheters will allow a selective blockade of involved nerve roots, optimize postoperative analgesia, and avoid complications from excessive epidural dosage and neuromuscular blockade. Familiarity with dermatomal landmarks as well as appropriate levels for blockade will ensure an adequate block and a satisfied patient.

Correct initial placement will prevent unnecessary blockade in undesirable regions and the complications that can result. Motor blockage of the lower extremities can limit early ambulation and its postoperative benefits. Urinary retention from epidural blockade necessitates prolonged catheterization and exposes the patient to an increased risk of urinary tract infection. In addition, correct initial placement can avoid excessive dosage of local anesthetic and resulting hypotension.

## Before Is Likely Better

If possible, preoperative epidural placement is preferred for improved pain control and ease of insertion. A painful wakeup after surgery can lead to respiratory complications, hemodynamic alterations, and psychological trauma for the patient. Preoperative confirmation of effective bilateral epidural levels ensure effective blockade. If used

during the surgery, especially preincision, preemptive analgesia may decrease incidence of postoperative pain. In addition, a preoperative epidural can decrease opioid use and its resultant side effects.

Postoperative epidural placement can be more challenging for the anesthesiologist and the patient. A painful patient may have difficulty positioning adequately for a postoperative epidural and may require placement in the lateral decubitus position. Tubes, lines, and drains also may limit certain positions or access to the spine. Postsurgical edema and/or dressings may also limit positioning and/or placement.

## Know What You Are Covering—Operative or Postoperative

Optimal levels for preoperative epidural placement may vary from postoperative placement. These discrepancies arise from the differences in between the incisional dermatomal levels and the visceral levels involved in the surgery itself.

For example, the Pfannenstiel incision for a Cesarean section is approximately at the T12–L1 dermatome. In contrast, an ideal dermatomal level for Cesarean section is up to T4 for adequate visceral coverage. A preoperative epidural should cover up to T4 for an adequate surgical block but a postoperative epidural should focus primarily on lower incisional pain. Even if you are not using your epidural for a surgical block, consider the visceral levels involved when placing your epidural to avoid need for opioids or an increased depth of anesthesia.

In contrast, a thoracic epidural for a video-assisted thoracoscopic surgery has similar incisional and visceral innervation and fairly similar levels for pre- and postoperative epidural placement. Ideal levels for a preoperative or postoperative epidural would be similar in this scenario. Below are our recommended dermatomal levels for operative and postoperative coverage. Levels may vary due to patients' personal anatomy and particular surgical needs.

| Type of Surgery | Recommended Operative Dermatomal Level | Recommended Postoperative Dermatomal Level |
|---|---|---|
| Thoracic surgery | T4 | T4 |
| Upper abdominal surgery | T4 | T7 |
| Caesarean section | T4 | T12 |
| Gynecologic, and | T6 | T10 |

| | | |
|---|---|---|
| urologic surgery | | |
| Transurethral resection of the prostate | T6 | Often unnecessary |
| Vaginal delivery | T10 | Often unnecessary |
| Hip surgery | T10 | L1 |
| Thigh surgery | L1 | L1 |
| Lower leg amputations | L1 | L1 |
| Foot and ankle surgery | L2 | L4 |
| Perineal and anal surgery | S2-S5 | S2-S5 |

## Landmarks for Placement and Assessment

Familiarity with landmarks and their corresponding dermatomal levels can aid with initial placement and analgesic assessment. Placement of an epidural catheter off these landmarks can held guide an anesthesiologist but they are not entirely accurate. Landmarks may be 1 or 2 levels off the suggested levels below due to anatomic variability.

Other options for precise placement include the use of fluoroscopy or ultrasound. These techniques can be used for patients with difficult anatomy and/or placement.

| Anatomic Landmark | Corresponding Dermatomal Level |
|---|---|
| Vertebral prominence | C7 |
| Spine of scapula | T3 |
| Inferior angle of the scapula | T7 |
| Iliac crests | L4 |
| Posterior inferior iliac spines | S2 |

## TAKE HOME POINTS

- Precise and thoughtful placement of epidural catheters will allow a selective blockade of involved nerve roots while avoiding excessive blockade.
- If you can, place the epidural preoperatively.
- Visceral innervation may vary from incisional innervation. Therefore, levels for preoperative and postoperative epidural blockade may differ.
- Anatomical landmarks can be helpful guides but are not 100% accurate. Ultrasound and/or fluoroscopy can be helpful adjuncts.

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# Know the Complications of Epidural Corticosteroid Injections

David A. Olsen, MD, Anne E. Ptaszynski, MD, and Toby N. Weingarten, MD

Epidural corticosteroid injections (ESIs) for radicular back pain have been performed since the 1950s and are one of the most commonly performed pain procedures today. Although complications are rare, the devastating sequela from any major complication requires absolute vigilance from the proceduralist. ESIs should only be offered for back pain likely to be responsive to steroid treatment.

Corticosteroids may be injected epidurally via the interlaminar, transforaminal, and caudal approaches. Common corticosteroids used include betamethasone, methylprednisolone, triamcinolone, and dexamethasone. These steroids vary in potency, duration of action, preparation (solution or suspension), and additives (benzyl alcohol or polyethylene glycol). These factors may have a role in potential complications.

Most complications are relatively mild and include headache, vasovagal reactions, transient increase in pain, dural puncture, and systemic effects such as hyperglycemia. A retrospective study in 2011 by McGrath of over 4,200 ESIs found a minor complication rate of 2.4%. Serious complications are rare but likely underreported. Arachnoiditis is an inflammation of the arachnoid mater, which leads to painful paresthesias and weakness. Severe neurologic injuries include paralysis, stroke, and transient blindness. Infectious complications, such as meningitis or epidural abscess, can be devastating or fatal. Careful and thoughtful performance of ESIs can reduce the rate of these complications.

## Neurologic Injury

Neurologic injury after ESI can have immediate or late onset. In cases of immediate-onset paralysis, either direct spinal cord trauma, or a vascular source such as vascular trauma or particulate embolism, is usually suspected.

Direct spinal cord injury is rare, with most cases occurring in the cervical spine. Neurologic sequela is significantly worse with injections into the spinal cord. Needle position should be confirmed prior to any injection. Prior cervical spine surgery or

large disc herniations can obliterate the posterior subarachnoid space and increase the risk of needle injury. Neurologic injuries are more likely in heavily sedated patients as these patients are less likely to respond to needle contact with the spinal cord.

There have been reports of catastrophic neurologic injury including paralysis, stroke, and death secondary to particulate injection into or injury of the arterial supply of spinal cord during transforaminal injections. All commercially available steroid suspensions contain particles large enough to occlude feeding capillaries and arterioles. The vessels of particular concern are radicular arteries feeding the spinal cord and, at the cervical level, the ascending cervical, deep cervical, and vertebral arteries. The anterior two-thirds of the cord are supplied by the anterior spinal artery. At the cervical level, the radicular and segmental medullary arteries are fed by the ascending cervical and deep cervical arteries. A cadaveric study demonstrated that 22% of the posterior portion of the cervical vertebral foramina, once considered the "safe" location for transforaminal needle placement, contained radicular cervical or segmental medullary arteries with risk of vascular injection.

In the thoracic and lumbar spine, the anterior spinal artery is fed by radicular arteries from the lumbar and intercostal arteries. Of particular concern is the artery of Adamkiewicz, typically located between T5 and L2 on the left. Its origin has considerable anatomic variability. Radicular arteries enter the spinal column through the foramen, putting them at risk during transforaminal injections. Previous spine surgery appears to be a risk factor for anterior spinal cord infarctions associated with epidural injections.

To limit the possibility of intravascular injection, consider using an interlaminar approach as the spinal arterial supply does not cross the dorsal epidural space. Transforaminal injections should be performed at the inferior aspect of the foramen, known as Kambin triangle to reduce vascular injection. Needle placement should be confirmed by administering contrast agent under live fluoroscopic imaging. Digital subtraction angiography provides an increased sensitivity in detecting intravascular injections. A test dose of local anesthetic can confirm intravascular needle placement by resulting in temporary paralysis, or, in cases of cervical injections, seizures. Use of a microbore attachment limits needle movement while syringes are changed between injections. A pencil-point spinal needle may decrease the risk of vascular cannulation. Corticosteroid solutions rather than particulate formulations may decrease the possibility of embolism during inadvertent intravascular injection. Cases of cervical anterior cord syndrome and cerebellar injury have occurred after cervical transforaminal epidural injections, despite needle placement using fluoroscopy and real-time computed tomography (CT). Transforaminal administration of particulate steroids in the cervical, thoracic, and upper lumbar spine should be performed only

with extreme caution and after careful consideration of the risks and benefits.

Late-onset paralysis may be due to several complications, including compression of the spinal cord from hematoma or epidural abscess; thrombosis due to vascular trauma may also be a source. A careful preprocedural history should be taken to exclude the use of anticoagulant or antiplatelet medication or an underlying bleeding disorder. Screening laboratory tests on all patients are not indicated. Minimizing needle manipulation in the epidural space further decreases the risk of vascular trauma. Because the spinal cord compression can be such a devastating complication, it is important to keep a high index of suspicion for epidural hematoma and abscess. Magnetic resonance imaging (MRI) is becoming the gold standard for diagnosis of these lesions, although CT with or without myelography is also useful. Immediate surgical decompression and evacuation is essential to reduce risk of permanent deficits.

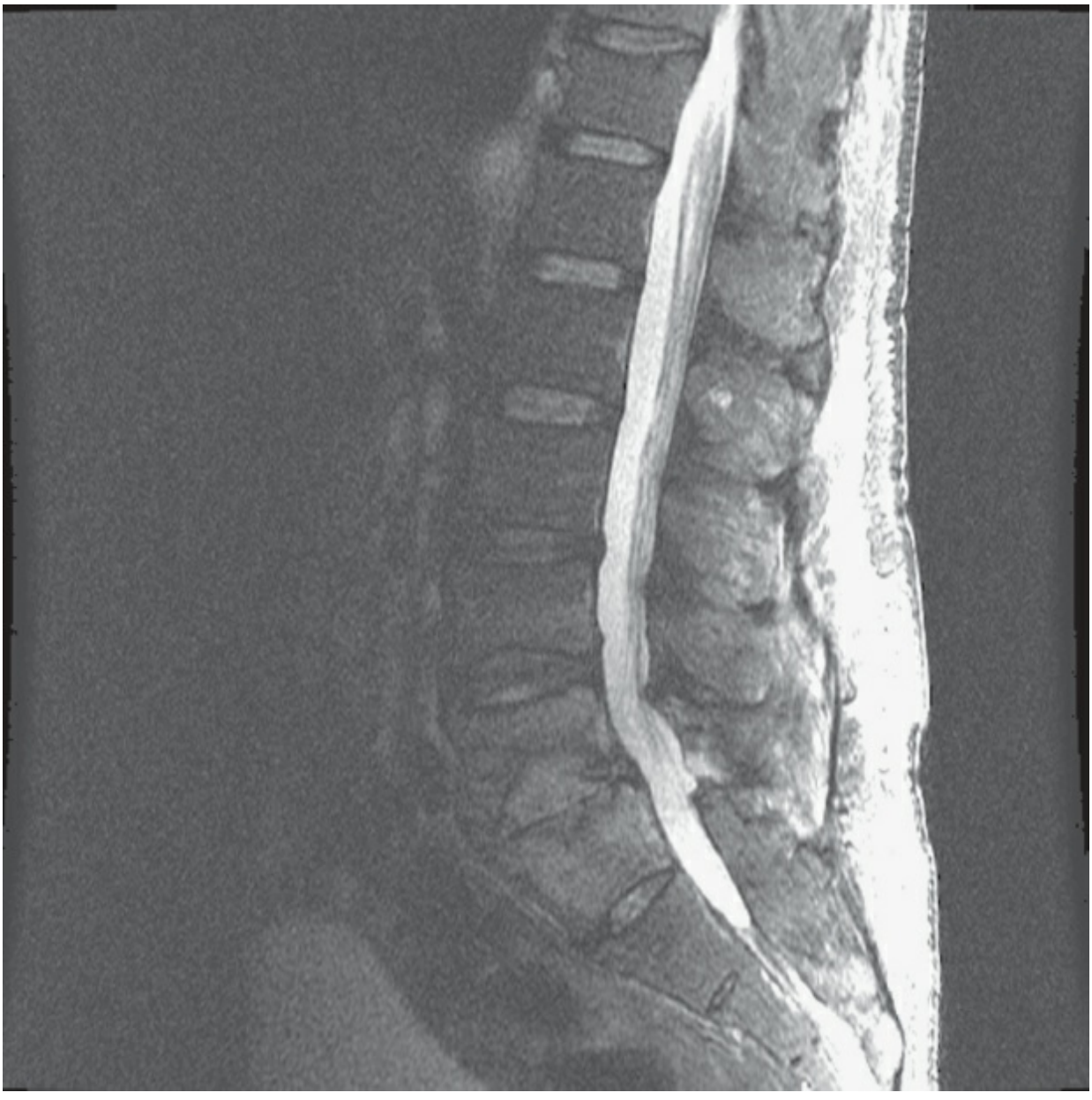

**Figure 181.1.** A T2 sagittal magnetic resonance imaging scan of the lumbar spine showing evidence of discitis after an intralaminar epidural corticosteroid injection at the L5/S1 interspace. The patient had a history of prior empyema and recurrent pulmonary infections.

## Infections

Infections due to epidural injections are rare but include meningitis, epidural abscess, and soft tissue or skin infections. In 2011, there was an outbreak of fungal meningitis associated with contaminated steroids. This outbreak, caused by Exserohilum rostratum contamination in preservative-free steroids from a single compounding pharmacy, has resulted in 750 cases of infection and 64 deaths and unfortunately highlights the devastation that spinal infections can cause. Risk factors appear to include remote extraspinal infections, an immunocompromised state, diabetes mellitus, chronic corticosteroid use, and cancer. Figure 181.1 shows MRI findings for a patient in whom discitis developed after an intralaminar ESI.

Several precautions should minimize the risk of infection. Meticulous adherence to sterile technique is an absolute. Skin preparation with chlorhexidine, which has been found superior to 10% povidone-iodine, should be strongly considered. While the incidence of infection is too low to recommend routine prophylactic antibiotics, administration of antibiotics active against Staphylococcus aureus and S. epidermidis to patients with risk factors could be considered. Needle passage should avoid superficial skin infections. The classic triad of fever, back pain or tenderness to palpation, and focal neurologic signs does not appear in all patients with epidural abscess. Most patients present with worsening back pain only, making a delay in diagnosis common. The clinician must maintain a high degree of suspicion in any patient complaining of back pain after an injection. Measurement of nonspecific markers of inflammation, such as sedimentation rate and C-reactive protein, are highly sensitive in identifying spinal infections. If epidural abscess is suspected, it is necessary to immediately perform MRI, CT, or CT myelography. These patients frequently need surgical intervention.

## Systemic Effects

Exposure to corticosteroids has both transient and long-term effects. Facial flushing, hyperglycemia, adrenal suppression, and Cushing syndrome have been reported after ESIs. Long-term exposure to corticosteroids can result in more serious complications such as depression of the immune system, osteoporosis, and hypertension. Using the lowest dose that is likely to be effective should minimize systemic adverse effects. Corticosteroid injections should be limited to a reasonable number per patient per year.

## Arachnoiditis

Adhesive arachnoiditis can occur after intrathecal administration of corticosteroids. The cause of arachnoiditis is unknown, but particulate corticosteroids in suspension and additives used as preservatives have been implicated. While there are no definitive reports of arachnoiditis following ESI, arachnoiditis can potentially occur if a portion of an ESI is delivered to the intrathecal space. Negative aspiration, however, does not guarantee that inadvertent partial injection into the intrathecal space will be prevented.

Administration of a contrast agent under fluoroscopy before injection of a corticosteroid can localize the needle in the epidural space. Use of a microbore attachment ("pigtail") limits movement of the needle during syringe changes, thereby limiting the chance of needle migration into the intrathecal space. Attention must be paid to the contents of the epidural kit and injectant to ensure that they do not contain neurotoxic agents or preservatives. Antimicrobial skin preparations should be allowed to dry before needle placement because these agents may be neurotoxic.

## TAKE HOME POINTS

- Epidural steroid injection is an established technique for the treatment of back and radicular pain.
- Mild complications include headache, vasovagal reactions, transient increase in pain, dural puncture, and systemic effects such as hyperglycemia.
- More serious complications include arachnoiditis, paralysis, infection, and the long-term systemic sequelae of steroid use.
- While serious complications from ESIs are rare, vigilance toward detecting potential complications is essential to help limit devastating complications.

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# If You Are New to Neuraxial and Peripheral Nerve Block Infusions—a View From Both Academia and Private Practice

Jordan B. Johnson, MD

The performance of neuraxial and peripheral nerve block procedures is becoming a fundamental skill of anesthesia and perioperative medicine. As anesthesiologists we should recognize the value of these tools in both the perioperative setting and in the inpatient and outpatient settings. Part of the beauty of these blocks is that they can be performed as a single-injection or they can be done as a continuous infusion to provide more long-term pain relief that can be titrated to effect. And both techniques can be done in both academic and private practice settings. While these blocks can provide significant benefit for our patients, it is important to understand the potential risks of these procedures. Here we will focus on some important considerations regarding continuous peripheral or neuraxial infusions.

## Why a Continuous Infusion?

Imagine you are in an operating room providing sedation for a patient having lateral foot surgery and that preoperatively you performed a single-injection popliteal sciatic nerve block. The block was successful as the primary anesthetic but the surgeon asks you why his patients no longer get catheters. The surgeon states that for a period of time in the past all of his patients having this type of surgery received blocks with continuous infusions and that to his recollection these patients did much better in the first few days postoperatively. One possible explanation for this could be the institutional changes that have made support for continuous infusions more difficult. Safely providing a service of continuous peripheral or neuraxial infusions often involves a robust interdisciplinary system that might not be available at every hospital. A firm understanding of the medications used, the risks, benefits, support needs, and appropriate patient selection is essential when considering using a continuous peripheral or neuraxial infusion. At my academic institution, Oregon Health and Science University (OHSU), nearly all neuraxial procedures for perioperative pain management are done as continuous

infusions (as opposed to interventional pain procedures by our chronic pain department). The vast majority are continuous epidural infusions, both for labor analgesia as well as qualifying surgeries though occasionally continuous intrathecal infusions are used as well. So, let us discuss some indications and contraindications for continuous neuraxial or peripheral infusions.

## Indications

- Need for prolonged pain control postoperatively, especially in notoriously painful surgeries (i.e., shoulder or lateral clavicle, wrist, ankle, large abdominal, or thoracic)
- Reduction in opioid consumption in at-risk patients (COPD, obstructive sleep apnea [OSA], etc.)
- Chronic pain patients with anticipated difficult pain control
- Secondary physiologic benefits such as improved respiratory mechanics in rib fractures or bowel surgery, and reduction in heart rate in high-risk cardiac patients
- Facilitate early ambulation and engagement in physical therapy
- Palliative care
- Opioid or other pain medication holidays

## Contraindications

- Patient refusal
- Coagulopathy
- Infection at potential catheter site
- Sepsis
- Lack of postprocedure caregiver for support
- Local anesthetic allergy
- Need for close monitoring of neuromuscular function postoperatively
- Concern for development of compartment syndrome
- Increased ICP (neuraxial)
- Anatomic anomalies
- Hemodynamic instability (neuraxial)

One of the obvious considerations when deciding between single-injection and a continuous infusion block is the level of support for the patient. This means your center needs to have a clearly defined system to provide not only technical support but also to be able to provide appropriate clinical assessment of patient-reported signs and symptoms. This system applies to inpatients and patients who are sent home with continuous infusion catheters. There needs to be someone (anesthesia-trained) who is available 24 hours a day, 7 days a week, for consultation by the patient or the patient's caregiver (someone at home with them or their providers and nurses if they are

inpatient). Most often, questions directed to this available anesthesia provider are related to technical aspects of the infusion. For example, the tape has come off, the catheter has come out or has become disconnected, or there is concern that visually the pump does not appear to be infusing. Other questions may be related to patient experience, such as increased pain (block wearing off), symptoms concerning local or systemic infection from the catheter, or local anesthetic systemic toxicity (LAST). Even less frequently, patients report that they have unsuccessfully tried to remove their catheter (it is painful to remove or they feel resistance) and sometimes they are too nervous or do not feel comfortable removing their catheters themselves and specifically request that an anesthesia provider do this for them, which would require them to be seen and evaluated in person. At OHSU, there is an in-house anesthesia MD (resident) available by rolling virtual pager around the clock. At night, this is the resident on OB, during the day it is the senior resident on his/her regional anesthesia rotation. The provider who placed the catheter likely will not be the one receiving pages or calls for troubleshooting. However, at my current private practice location, this system does not exist. Anesthesiologists do occasionally place epidural catheters and peripheral nerve block catheters with the understanding that the performing physician needs to be available on phone or pager until the catheter is removed either by the patient at home or a provider in the hospital. Patients also need to be well educated with clear instructions on what to do with their infusions, as many patients are expected to self-manage their infusions at home and remove the catheters themselves with the help of a caregiver. This expectation may provoke fear and anxiety for some patients. At OHSU, patients receiving indwelling catheters all watch a short informative slideshow about the specific indwelling technique they have and this helps to standardize the information that each patient is exposed to. Building a support system that reliably provides around-the-clock technical and medical support involves coordination of the anesthesiology, surgical, hospitalist, and emergency departments.

## Neuraxial Infusion of What?

The primary medication used in neuraxial or peripheral infusions is most often a local anesthetic. When performing a single-injection neuraxial or peripheral block, other medications can be added to the injectate to try to increase the duration of analgesia. These additives often include corticosteroids (i.e., dexamethasone) and other analgesics such as opioids or ketamine, clonidine, and epinephrine, although aside from opioids most of these are not routinely added to continuous infusions. The choice of medications for continuous infusion may be based on anatomic location and typically contains a local anesthetic, an opioid, or a combination of both. Opioids are often added to neuraxial infusions and studies have shown that neuraxial infusions provide better pain

relief when they contain both a local anesthetic and an opioid rather than either of the medication alone. In addition, clinical situations exist in which neuraxial infusions containing only a local anesthetic or an opioid alone are appropriate. For example, a patient who may be at risk for significant hemodynamic instability such as hypotension resulting from intraoperative blood loss may not tolerate a sympathectomy caused by neuraxial local anesthetic, and therefore an opioid-only solution is more appropriate. Another patient for whom an opioid-only infusion might be indicated is a patient for whom any degree of sensory or motor block would be undesirable. In contrast, a patient who is overly sedated and hypoventilating may not tolerate additional respiratory depression from neuraxial opioids and therefore may be more appropriate for a solution containing a local anesthetic alone. In contrast to neuraxial infusions, continuous peripheral nerve blocks most often contain only local anesthetic. One reason for this is that neuraxial blocks allow the delivery of opioids more directly to their desired site of action—the spinal cord, whereas peripheral nerve blocks do not. Additionally, as is common at our institution, you may be sending a patient home to self-manage their peripheral nerve block infusion which would preclude the infusion containing an opioid for safety and legal reasons.

Deciding which specific local anesthetic or opioid to use and at which concentrations involves consideration of multiple factors. Most local anesthetics exist in different concentrations and the concentration will affect the density of your patient's sympathetic, sensory, and motor blockade. Local anesthetics of higher concentrations may also potentially expose your patient to greater risk of LAST depending also on body weight, infusion rate, or the unfortunate event of intravascular placement or migration of a catheter. Higher than desired local anesthetic concentrations or infusion rates could also lead to "high" or "total spinals" with adverse neurologic, respiratory, and cardiac effects. The "density" of blockade directly correlates with the concentration of local anesthetic and this concept is very evident in epidural infusions for labor analgesia. When I am called to bolus a labor epidural, I select the concentration of local anesthetic (typically bupivacaine 0.5%, 0.25%, or 0.125%) based on the laboring patient's desired sensory and motor blockade.

Many opioids are commonly used in neuraxial infusions including morphine, hydromorphone, fentanyl, and sufentanil. The default at our center is hydromorphone, but morphine and sufentanil are often used. In contrast to fentanyl and sufentanil, morphine and hydromorphone tend to be associated more with pruritis that may require treatment or the substitution of a different opioid. For opioid-tolerant patients, you can consider using a more lipophilic opioid such as sufentanil or fentanyl which tends to be more rapidly absorbed at the spinal cord level and have fewer systemic side effects than the more hydrophilic (morphine, hydromorphone) opioids. If a neuraxial infusion is

not providing adequate pain relief or is causing intolerable side effects and the proper function and location of the catheter system has been confirmed, then you should consider making medication or concentration changes.

## Common Neuraxial Infusion Concentrations

- Bupivacaine—0.1% to 0.15%
- Ropivacaine—0.1% to 0.2%
- Morphine—0.05 to 0.1 mg/mL
- Sufentanil—1 to 2 mcg/mL
- Fentanyl—2 to 5 mcg/mL
- Hydromorphone—10 to 20 mcg/mL

## A Peripheral Nerve Block Infusion of What?

Deciding what medication to use in a peripheral nerve block infusion is seemingly more straightforward as most of these infusions usually contain only local anesthetic. Again, remember that patients are often sent home with these catheters that might be the single most important factor in determining the solution for the infusion. Our center uses ropivacaine-only infusions at a concentration of 0.2% and although our home pumps do have a dial on them allowing the adjustment of the rate of infusion, this function is disabled for patients. The maximum infusion rate the pump can provide is an important consideration in deciding the local anesthetic concentration if the patient will be allowed to adjust the rate at home, though I do not recommend this be common practice as it places the patient at potential risk of LAST or local nerve toxicity. As previously discussed, potential risks of local anesthetics such as cardiotoxicity, LAST, or the density of sensory or motor blockade should also be considered when deciding what local anesthetic or concentration to use.

## Do I Make the Solution Myself?

Ideally, infusions are ordered by the anesthesiologist but the solution is prepared by the pharmacy. This provides one less opportunity for a medication error as a power-of-ten dose increase can have catastrophic consequences in such an event as administering an epidural dose of local anesthetic inadvertently into the intrathecal space. Some centers may not have a dedicated pharmacy to prepare these solutions; therefore, you may have to calculate the dose and make the solution yourself. If this is the case you should always have another medical professional double check your calculations and dosages prior to administering the medication to the patient.

## What Can Go Wrong?

Risks pertaining specifically to the performance of neuraxial and peripheral blocks are discussed in Chapter 157. Local anesthetic volumes and total doses in intrathecal infusions are much smaller than other routes of administration. Dosing errors here can have potentially fatal consequences in the form of hemodynamic instability or high or total spinal requiring emergent airway management and resuscitation. Additionally, dosing errors in opioid concentrations can also be dangerous in the form of oversedation and respiratory depression leading to respiratory failure and cardiac arrest.

Patients who are sent home with continuous peripheral nerve block catheters are also potentially at risk for local anesthetic-related complications. A patient whose motor and sensory block is too dense may be prone to further injury such as abrasions, cuts or burns, or peripheral nerve compression and they may be unaware of such injury due to lack of sensation. Additionally, excessively dense blocks may prevent your patient from participating in expected rehab programs soon after surgery. Most concerning of the risks of home infusions is the potential for intravascular infusion with adverse effects like LAST, cardiac and respiratory toxicity. Proper labeling of these catheters is essential to avoid unintentional administration of the wrong medications or doses through the catheter. Some of these catheters are not MRI compatible and should be removed if an MRI is needed.

## Troubleshooting Continuous Infusions

- History and physical exam for signs and symptoms of infection, drug reaction, and toxicity
- Inspect catheter site for signs of migration, injury, infection, or local drug reaction
- Check catheter location with ultrasound (peripheral), or fluoroscopy with contrast (neuraxial)
- Test efficacy of catheter with a safe test dose followed by assessment of analgesic blockade
- Discuss pain control goals with your patients to ensure reasonable expectations are set

## In Summary

Continuous neuraxial and peripheral nerve blockade can be a valuable tool to provide excellent patient care in the areas of analgesia, postoperative recovery as well as patient satisfaction. Everything we do should be decided on a case-by-case basis and each patient's individual factors including medical history and personal preferences should be taken into consideration as well as should potential risks for each patient when you decide if a continuous infusion is the best option and what medications you

will use in the infusion.

**One more time for new practitioners—personal notes from Dr. Johnson on how he organizes and summarizes his own practice:** Again, regarding continuous peripheral nerve blocks, there are surgeries where my **first thought** is that the patient may benefit from this mode of analgesia. These would be shoulder or lateral clavicle surgery, wrist surgery, knee surgery, and ankle surgery. **I think in general, continuous peripheral nerve blocks come to my mind with orthopedic surgery.** Additionally, in patients who are opioid-tolerant and whose pain may be inadequately treated with additional opioids, I will consider continuous peripheral nerve block. Patients who have comorbidities such as OSA or are at higher risk of hypoventilation and respiratory compromise from additional opioids may be good candidates for this modality regardless of the type of surgery.

For continuous neuraxial infusions the above considerations are as relevant, I consider the anatomical site of surgery and how pain there may directly relate to their ability to ventilate adequately after surgery. For instance, a patient who is having a thoracotomy likely will have poor respiratory mechanics postoperatively without a continuous epidural infusion. This is multifactoral—the lung tissue trauma itself, intense chest wall pain causing splinted breathing and worsening atelectasis, and likely respiratory depression from opioids play roles in this. In the absence of contraindication, an epidural infusion placed preoperatively likely will decrease the overall opioid dose required intraoperatively, will better manage chest wall pain allowing the patient to breathe more adequately and improve pulmonary mechanics and decrease the total opioid requirement postoperatively. I consider these factors for abdominal surgery as well.

But here is the thing…I can see, now working in a busy private practice, that the prospect of placing a continuous peripheral nerve block or neuraxial infusion and ensuring that I am available as the sole provider for a number of days (typically 72 hours for peripheral nerve blocks or up to 5 to 7 days for neuraxial) might possibly discourage providers in this setting from utilizing this modality. However, as I stated above, patient experience and patient feedback are quickly becoming more and more powerful as drivers for hospital practices, reimbursement, and accreditation. Offering this modality and duration of pain relief for patients will become more important and plays into the concept of a "surgical home" for patients, where they are not just cared **for as Case # 11747** on some random date, but their preoperative care is managed to optimize them for surgery and they are well-cared for postoperatively as well.

## TAKE HOME POINTS

- A robust system of around-the-clock support needs to be in place for patients with continuous peripheral or neuraxial infusions and this requires coordination among all potential specialties involved. To review, at OHSU all perioperative and ward nurses who may be involved with these patients have the knowledge and materials available to assist patients with their catheters and infusions.
- For continuous neuraxial blockade consider a local anesthetic in combination with an opioid to optimize analgesia, although in certain clinical situations a solution containing either a local anesthetic or an opioid alone may be appropriate.
- For continuous peripheral nerve blockade, consider a local anesthetic-only solution.
- To minimize dosing and medication errors, ideally solutions are mixed by the pharmacy, but if this is not possible ensure that a two-person check is performed prior to administering the medication to your patient.
- Have a good working knowledge of the pharmacology and dosing of medications to be administered including toxic dose calculations for each local anesthetic.
- Continuous infusions will require postprocedure caregiver presence and proper patient education with goals and safety issues thoroughly discussed.

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# What to Do With a Prolonged Block

Zheyan (Jenny) Chen, MD and Ryan Ivie, MD

"I still can't feel my arm!" "My foot is still numb and tingly!" Sometimes the nerve blocks we perform for our patients outlast their welcome. When nerve symptoms persist longer than the patient expects, we usually hear about it from the surgical team, perhaps on postop day 2 rounds after the patient received a single injection block. Perhaps on postop day 6 at the first office visit following ambulatory surgery. In this chapter we'll discuss what to do when you learn that a patient is reporting a prolonged nerve block.

## Talk to the Patient!

Call the patient at home or go to their bedside. You'll want to clarify the symptoms he/she is having. Are they experiencing a motor block, sensory block, or paresthesias? Has there been any change in these symptoms? Most blocks wear off progressively with motor function returning early and tingling "pins and needles" sensations prominent as the block resolves.

Where are the symptoms located? Identify as best as possible over the phone the specific location of the symptoms. If the patient is still in the hospital, do a thorough sensory exam (e.g., sensation to cold and/or pinprick) and motor exam of the affected and normal extremity.

There are three sources of potential nerve injury in a typical perioperative course: (1) peripheral nerve block, (2) surgical injury, and (3) positioning injuries. Many times when we are called about prolonged blocks, the symptoms are in the distribution of nerves that were not blocked (e.g., symptoms in the sciatic distribution in a patient who received only a femoral block). Identify the surgical procedure performed and consider the likelihood of surgical injury. Different surgeries are associated with different risk of nerve injury, but in general, the risk of surgical nerve injury appears to be as high or higher than the risk of peripheral nerve block–related injury. The tourniquet is another potential source of surgical nerve injury, especially when used for a long duration at high pressure. Via a similar mechanism, postoperative wound dressings and casts can occasionally result in nerve injury. Assess for tightness and swelling around the edges

of the dressings.

## Review the Chart

Sometimes perception of a prolonged block is merely a misunderstanding of the expected time course of block resolution. You'll want to distinguish between normal, anticipated resolution of a block and nerve symptoms that outlast what you would expect for a routine nerve block.

What local anesthetic was used? Was it a single shot or a catheter? Different local anesthetics have different expected durations. A rough estimate of the anticipated duration of analgesia from a single injection peripheral nerve block is 4 to 6 hours with lidocaine or mepivacaine, 10 to 12 hours with ropivacaine, and 12+ hours with bupivacaine. Catheter infusions prolong the analgesia beyond the duration of the initial injection, and resolution of analgesia after pulling the catheter is typically more rapid due to the delivery as a slow infusion rather than a large-volume bolus. There are many variables other than local anesthetic type and delivery method that impact the anticipated duration of an uncomplicated block and make the precise definition of a normal duration impossible.

What volume, concentration, and additives were used? Other injectate factors that impact duration include the volume of local anesthetic and the concentration used (e.g., 0.5% ropivacaine provides a more prolonged block compared to 0.2% ropivacaine). The presence of adjuvants can prolong the nerve block for several hours beyond the typical time course of the local anesthetic alone. Dexamethasone, clonidine, dexmedetomidine, and buprenorphine may all be used to intentionally prolong a nerve block. Note that with dexamethasone, intravenous administration is effective in prolonging the duration of a nerve block, so intraoperative nausea prophylaxis may even be the culprit for a block that's lasting longer than anticipated! Liposomal bupivacaine or other depo forms of local anesthetic are another potential source of prolonged block. Although data are conflicting and dependent on the injection site, these long-acting formulations have the possibility of extending local anesthetic effect up to 72 hours. And even if it wasn't used in the nerve block, check the operative report to see if the surgeon used liposomal bupivacaine in their infiltration of the surgical field.

What nerves were blocked and with what technique? The type of block performed also impacts duration. For example, a normal sciatic nerve block can have a duration that is 1.5 to 2 times longer than a brachial plexus block. The specific needle target site for injection is another variable, as injections closer to the nerves may result in slower diffusion away from the nerve fibers. This is seen with popliteal sciatic injections, where injection deep to the paraneural sheath results in a longer-duration block compared to injections superficial to the paraneural sheath.

Anything atypical noted about the block procedure? An injection unintentionally deep to the epineurium of a nerve (intraneural but not intrafascicular) may last longer than anticipated, even in the absence of a true mechanical or chemical nerve injury. Similar to an injection within the paraneural sheath, this is likely due to close proximity of the local anesthetic to the fascicles and due to the epineurium serving as a barrier that slows diffusion away from the nerve fibers. An injection deep to the epineurium is nearly impossible to identify in retrospect. Depending on the site of the block, the quality of ultrasound image, the volume injected, and the cognizance of injection pressure and patient comfort, an intraneural but not intrafascicular injection could go unappreciated.

An injection unintentionally deep to the perineurium of a nerve fascicle (intraneural and intrafascicular) is more likely to result in noticeable (and hopefully documented) abnormalities during the procedure. Paresthesias or pain on injection, high injection pressure, nerve swelling visualized on ultrasound may indicate intrafascicular injection. The patient's recollection of the procedure may be an additional clue, but it can be hard to discern the meaning of recalled discomfort given the wide variation in patient tolerance of normal, uncomplicated blocks. Regardless of whether or not an intrafascicular injection is appreciated at the time of the procedure, a nerve injury could have occurred and could be the cause of the prolonged neurologic dysfunction.

## Is It a Nerve Injury?

Frequency of nerve injury due to peripheral nerve block is variable based on the study methodology, the type of nerve block performed, and the nerve block technique (e.g., ultrasound-guided vs. nerve stimulation-guided). The incidence of significant peripheral nerve injury has been reported as anywhere from 0.02% to 0.2%. Incidence of nerve dysfunction in the initial 1 to 2 weeks may be dramatically higher—as high as 14% has been reported! Time heals the vast majority of these injuries, with 98% to 99% resolution by 1 year. The likelihood of complete resolution is higher if the symptoms are purely sensory.

How can a nerve block cause nerve injury? There are several mechanisms, including direct needle trauma to the nerve fibers, the inherent neurotoxicity of the local anesthetic, and nerve ischemia due to pressure from the injected local anesthetic, hematoma, or concomitantly administered vasoconstrictors. The cause may be related to the way the nerve block was performed, as with intrafascicular injection or unappreciated vascular injury. Alternatively, an injury can be due to nerve exposure to local anesthetic in the absence of procedural error, especially in nerves that are pathologic at baseline.

Who's at higher risk? Some aspects of the patient's medical history may predispose

them to nerve injury. Diabetic patients have a higher likelihood of sustaining a nerve injury, regardless of whether the peripheral nerve block, the surgery, or a positioning issue is the culprit. This is likely due to subclinical nerve dysfunction and impaired blood supply to the patient's nerves. Similarly, pre-existing nerve dysfunction due to other etiologies predisposes a patient to nerve injury. A patient with a known peripheral nerve disorder would probably not have been offered a nerve block for this reason, but don't forget to assess every patient with a suspected nerve injury for the presence of pre-existing symptoms of nerve dysfunction in the affected or unaffected extremities. An undiagnosed neurologic disorder may be revealed by a careful history!

## What Do I Tell the Patient?

Reassurance is key! The majority of prolonged nerve blocks will resolve with a complete return to normal function. If the complaint of nerve dysfunction was reported very early (e.g., 1 to 3 days after anticipated resolution) and are mild (e.g., slightly diminished sensation), resolution may be very rapid. If the nerve dysfunction has already persisted a few weeks or the symptoms are more pronounced (e.g., complete sensory anesthesia), this may suggest a more significant injury. Resolution is still very likely, but it may take several weeks to months. More profound injuries, especially those involving muscle weakness, may take several months to resolve and there is a chance of incomplete resolution. Since most prolonged blocks are reported early (i.e., prior to or at the first postoperative surgical office visit), reassurance is typically an important step in easing the patient's anxieties and setting realistic positive expectations. When a nerve injury is suspected, many patients also appreciate an explanation of how nerve injuries happen and why it might have happened to them.

How should the patient follow up? In those cases where the timing of nerve dysfunction is still within reason given the block site, technique, and local anesthetic and adjuvant(s) used, then a follow-up phone call in a few days is likely all that is necessary. But when the symptoms are deviating from the anticipated block duration, it is important to ensure in-person follow-up. Despite the likelihood of a good outcome, proper assessment and documentation of the extent of the nerve injury is important. A thorough history and physical examination should be performed. This will allow accurately tracking improvement with time, can help identify the potential etiology, and can establish the severity of a suspected nerve injury in order to guide prognosis and the need for further diagnostic studies. The in-person history and physical can occur at a scheduled surgical office visit, by scheduling a visit at an anesthesiologist-staffed clinic (e.g., Chronic Pain Clinic or Preoperative Medicine Clinic), by arranging to have the patient seen by the Regional Anesthesia team in the block bay, or via referral to Neurology or to Physical Medicine and Rehabilitation (PMNR).

Mild symptoms that aren't bothersome to the patient or interfering with their daily life are appropriate for follow-up with the surgeon and a repeat phone call from the anesthesiologist. More significant symptoms are best evaluated by an anesthesia provider familiar with nerve blocks, preferably within a few days of the symptoms being reported. In patients for whom neuropathic pain is a symptom of the prolonged nerve dysfunction, follow-up in a Chronic Pain Clinic should be established. Some anesthesiologists consult a neurologist for all suspected injuries so that an accurate neurologic exam is recorded, but most request a referral only for injuries that appear profound (e.g., motor block) or are persistent (e.g., persisting at 2 to 4 weeks postoperatively). Regardless of the method of follow-up selected, the patient should be given contact information to easily contact a health care provider in case any symptom worsening is experienced.

Are there additional tests? For severe or persistent symptoms, additional diagnostic studies can be performed. The two common tools are electrophysiologic studies and magnetic resonance imaging. Electrophysiologic studies, such as electromyography and nerve conduction studies, are the gold standard for evaluating suspected nerve injuries. Both neurologists and PMNR clinicians can perform and interpret electrophysiologic studies. These studies can aid in identifying pre-existing neurologic dysfunction on nonoperative extremities, help localize the specific site of nerve injury, and allow for more accurate assessment of prognosis. Electromyography will not provide a complete picture of the nerve dysfunction if performed too early, but can provide helpful baseline data. The consulting providers can best guide the appropriate timing of electrophysiologic studies to yield the most detailed and prognostic data. Finally, referral to a surgeon specializing in peripheral nerves may be considered for injuries persisting for several months.

## TAKE HOME POINTS

- Call or visit the patient as soon as possible.
- Get a detailed history of the symptoms with attention to quality, severity, and anatomic distribution. Document this!
- Determine if the symptoms are expected given the block site, technique, and local anesthetic and adjuvants administered. Document this, too!
- Assess if there are surgical etiologies or positioning factors that better explain the symptoms.
- If you suspect nerve injury, reassure the patient that most injuries resolve and notify your risk management and quality-assurance staff that there is a possible block complication.
- For the mildest of symptoms, schedule a follow-up phone call. For everything else,

ensure an in-person follow-up for a thorough physical exam, for example, in your Chronic Pain Clinic.

- Consider referral for additional testing (i.e., electrophysiologic studies) for severe symptoms, such as those with motor involvement, and persistent symptoms (e.g., >2 to 4 weeks postoperatively).

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# Regional Anesthesia in the ICU—What Should We Use and When Should We Use It?

Benjamin L. Antonio, DO MBA

A 76-year-old female with a history of chronic obstructive pulmonary disease (GOLD Stage III) requiring home oxygen (2 L NC), hypertension, chronic atrial fibrillation, and pulmonary hypertension tripped in the parking lot and fell after visiting her primary care provider for productive cough she had been experiencing over the previous 3 days. She immediately experienced pain in her left chest. She was taken to the emergency department. An EKG was obtained and was significant only for left ventricular hypertrophy. CXR revealed left-sided fractures of ribs 6 to 8 as well as the possibility of an infiltrate in the left upper lobe. Since admission to the ICU yesterday, she has become progressively more dyspneic. She continues to report significant left-sided chest pain with inspiration despite treatment with low-dose hydromorphone. Vitals signs: BP = 176/52 mm Hg, RR = 27 breaths/min, $SpO_2$ = 88% on 6 L NC. She is awake, alert, and oriented to person, time, and place.

## Introduction

Regional anesthesia is underutilized in the critical care environment. Given the known benefits of improved pain control, more attention needs to be paid to the performance of regional anesthesia in critically ill patients. Few studies have specifically examined the outcomes of regional anesthesia in intensive care unit patients. Most studies including ICU patients have examined the risks and benefits of epidural anesthesia or analgesia in the postoperative ICU patient. In fact, a recent systematic review revealed that epidural analgesia combined with general anesthesia reduces mortality in postoperative patients. Major risks of performing regional anesthesia in ICU patients include issues of anticoagulation, sepsis/bacteremia, immunosuppression, potentially increased risk of nerve injury in sedated and noncooperative patients and multisystem organ failure. Purported benefits of regional anesthesia in the ICU are improved analgesia, decreased sympathetic tone, decreased thrombosis, and earlier mobilization.

Regional anesthesia can be safely utilized in the ICU patient if you carefully consider the pharmacodynamic and pharmacokinetic effects of impaired organ function. Anesthetic drug metabolism may be altered by concurrent medications or by impaired metabolic activity of failing organs. You must pay attention to adequate and appropriate dosing. Acute and/or chronic respiratory impairment may be magnified during regional anesthesia due to impaired phrenic nerve function or preexisting respiratory impairment. **On the contrary, if you have a trauma patient with rib fractures, analgesia from regional block may improve your patient's lung mechanics and obviate the need for positive pressure ventilation. Decreases in the need for opiate medications has facilitated weaning from mechanical ventilation and reduced the risk of nosocomial pneumonia.** Hematologic derangements are common in the ICU patient as a result of medications and other pathophysiologic processes. While thrombocytopenia and coagulopathy are common in the ICU, the high risk of DVT/PE in ICU patients accounts for the high utilization of anticoagulant therapies. Please consider the risks of performing regional anesthesia in the context of impaired hemostasis, depressed immune function, and other co-morbidities. In the end, the risk benefit ratio of regional anesthesia in the ICU patient must be carefully examined.

## Specific Considerations of Regional Anesthesia in the ICU

### Analgesia and Delirium

**Should you consider regional analgesia in patients at high risk for the development of delirium?** We think so. Regional analgesia may be beneficial in ICU patients requiring procedures and/or pain control. The importance of adequate pain control in the ICU is increasingly recognized. Inadequate pain control has been associated with the development of delirium, but the misuse of opiates has also been associated with an increased incidence of delirium in the ICU population. It is difficult to distinguish the deliriogenic effects of opiates in the ICU patient from other commonly utilized deliriogenic medications such as benzodiazepines. Elderly patients are at increased risk for brain dysfunction and may have preexisting cognitive impairment. The development of daily-awakening protocols and the search for less deliriogenic sedative agents highlights the growing appreciation of the proper use of sedative-analgesic medications in the mechanically ventilated ICU patient. The association of delirium with poor ICU outcomes and increased mortality, suggests regional analgesia in the ICU will confer outcome benefits.

### Opiates and Cancer

**Should you reduce systemic opiate usage in critically ill cancer patients?** Opiates

are immunosuppressive and may worsen outcomes in cancer. Opiates are known to impair both cellular and humoral immunity. They suppress the function of natural killer cells whose role is integral in inhibiting tumor progression. It is hypothesized that regional anesthesia may be associated with improved outcomes in cancer due to their opioid sparing effects, attenuation of the stress response, and absence of inhalational anesthetics. It is unclear whether the choice of opioid and/or the type of cancer are important factors. More studies are needed to examine the clinical relationship between opioids, immunosuppression, and cancer recurrence.

## Regional Anesthesia/Analgesia and Sympathetic Tone

**Are reductions in sympathetic tone beneficial to ICU patients?** Mechanisms of benefit include a reduction in sympathetic output with decreases in heart rate, arrhythmias, vascular tone, and improvements in organ perfusion. The ability of epidural analgesia to reduce sympathetic thoracic outflow may have beneficial effects in the patient with coronary artery disease. Reductions in sympathetic tone and a decrease in the utilization of opioid-based medications are thought to reduce the duration and incidence of paralytic ileus in patients undergoing abdominal surgery. However, placement of a thoracic epidural and its sympatholytic effects must be carefully considered. Critically ill patients are often dependent on sympathetic tone for adequate blood pressure. The reduction in sympathetic tone may foster the development of severe hypotension and an impaired compensatory response. Judging intravascular volume is clinically challenging in the ICU patient, and attaining adequate intravascular volume may be precluded due to existing cardiac and pulmonary impairment. Epidural analgesia with local anesthetics is contraindicated in patients with hemodynamic instability, but the analgesic effects of epidural opioids and/or clonidine may confer the benefit of epidural analgesia to hemodynamically unstable patients.

## Regional Anesthesia/Analgesia and Mechanical Ventilation

Improved analgesia without the use of large doses of IV opiates promotes weaning from the ventilator and reduces the incidence of VAP in abdominal and thoracic surgery patients. Paravertebral, intercostal, and epidural analgesia may also facilitate better lung mechanics and decrease the need for mechanical ventilation in patients with rib fractures. The use of regional analgesic techniques in the elderly patient with rib fractures may have increased benefit as their mortality and morbidity is increased when compared to younger patients. The use of thoracic epidural analgesia in patients undergoing abdominal aortic surgery was associated with better pain relief, decreased time of mechanical ventilation, and decreased rates of VAP. Decreased time on the ventilator decreases the risk of ventilator-associated pneumonias and allows for earlier

and improved mobility of the ICU patient. The development of the ABCDE protocol is an example of the recognition among providers that improved analgesia, decreased delirium, shortened duration of mechanical ventilation, and early mobilization will improve outcomes. The ABCDE protocol requires a coordinated effort of all providers in the ICU to perform spontaneous awakening trials and spontaneous breathing trials in timely fashion to reduce delirium, promote decreased ventilator dependence and encourage earlier mobilization. The provision of an appropriate level of analgesia is an integral part of the protocol, and the lack of sedating effects of regional analgesia may facilitate its application in the ICU.

## Regional Anesthesia/Analgesia in the Septic/Bacteremic Patient

Sepsis is often associated with bacteremia, thrombocytopenia, coagulopathy, and impaired hepatic and renal function. Significant impairment of metabolic and elimination and excretion mechanisms in the kidney and liver highlight the importance of the proper dosing of medications. Placement of an epidural catheter in a patient with sepsis/bacteremia remains controversial even after antibiotics have been initiated and the patient exhibits signs of clinical improvement. Although the risk of abscess following epidural is rare, clinical consequences may be catastrophic. The etiology is unclear, but in most cases of epidural abscess, the infection may have originated from a remote site spreading to the neuraxial space via the bloodstream and may not have migrated along the insertion site itself. Recognition of epidural abscess may be made more difficult in the ICU patient where a constellation of symptoms and sedation may confound and prevent early diagnosis.

Examination of the risk of infectious complications following peripheral nerve blocks and continuous catheter techniques has been less well studied. Aseptic technique, proper management of catheter sites, use of bacterial filters, and the bactericidal properties of local anesthetics may account for the relatively rare occurrence of epidural abscess and other infectious complications attributed to regional analgesic techniques. The risk-benefit ratio of regional anesthesia must be examined before performing the regional technique.

## Regional Anesthesia/Analgesia in the Immunocompromised Patient

Immunocompromise results from a variety of conditions that are common in the ICU patient. Neoplasm, solid organ transplantation, HIV, and diabetes commonly cause immunosuppression in the ICU. There is a paucity of data examining the outcomes of regional anesthesia in immunocompromised ICU patients. There are infectious and

noninfectious risks to consider. The lack of an intact immune system suggests that symptoms of infectious complications of regional anesthesia may not be as visible, delaying early recognition and treatment. Immunocompromised patients may present with thrombocytopenia, disseminated intravascular coagulation (DIC), and other blood dyscrasias. In addition, metastases to bone may predispose the spinal cord to injury during neuraxial block. Peripheral neuropathy is common following treatment with certain types of chemotherapy and may complicate the performance of peripheral nerve blockade and assessment of regional analgesic complications.

## Regional Anesthesia/Analgesia in the Critically Ill Patient With Impaired Homeostasis

Although the incidence of neurologic dysfunction from hemorrhagic complications is relatively rare, clinical consequences are potentially catastrophic. The use of anticoagulant, antiplatelet, and/or thrombolytic therapies are common in the ICU and pose a contraindication to neuraxial techniques. Please consider the risk of vascular injury when performing peripheral nerve blockade in these patients. You should consider if the artery is at a compressible or a noncompressible site and utilize an ultrasound-guided technique whenever possible. Lastly, review published consensus guidelines on the management and performance of regional anesthesia techniques in patients on anticoagulant therapies.

## Specific Peripheral Nerve Blocks in the ICU

There is a dearth of evidence examining the outcome of specific peripheral nerve block techniques in ICU patients. The critically ill patient may benefit from upper-extremity brachial plexus blocks and lower-extremity blocks. Improved analgesia, decreased opiate requirements, and attenuation of the stress response will be beneficial to the ICU patient. Developing indications include analgesia for painful bedside procedures. The use of topical lidocaine given in a retrograde direction through the suction tubing 20 minutes prior to removal of wound vacuum-assisted closure devices was found to be beneficial in trauma patients. Other developing indications include analgesia for the reduction of fractures, burn injuries, and for improving perfusion to ischemic limbs. Although there has been concern that the obscuration of pain as a presenting symptom in the development of acute compartment syndrome leads to a delay in diagnosis, this is unlikely if the patient is monitored properly.

Before performing peripheral nerve blocks, you should consider the following:

What is the risk of placing peripheral nerve blocks and catheters in sedated patients or in those with varying levels of consciousness?

Is it possible to place the patient in the appropriate position for performance of the peripheral nerve block? Are you comfortable and experienced in placing a block with the patient in the lateral position?

What is the risk of pneumothorax and does the patient already have a preexisting pneumothorax on the contralateral side?

When performing an interscalene block consider the effect of ipsilateral phrenic nerve paralysis in a patient with respiratory impairment or severe COPD?

**Table 184.1 ■ Peripheral Nerve Blockade in the ICU**

| Pnb | Indications | Contraindications | Challenges |
|---|---|---|---|
| ISB | Shoulder, arm pain | Untreated contralateral pneumothorax, Dependence on diaphragmatic breathing, Contralateral vocal cord palsy, Local infection at puncture site | Ipsilateral IJ or SCV CVC, tracheostomy site, Horner syndrome may obscure neurologic assessment, Block of ipsilateral phrenic nerve |
| Infraclavicular | Arm, hand pain | Severe coagulopathy, Untreated contralateral pneumothorax, local infection at puncture site | Steep angle for catheter placement, difficulty with the close proximity of SCV CVCs |
| Axillary | Arm, hand pain | Local infection at puncture site | Arm positioning, maintaining catheter site |
| Supraclavicular | UE pain | Untreated contralateral pneumothorax, local infection at puncture site | Risk of pneumothorax, subclavian artery injury |

| | | | |
|---|---|---|---|
| Femoral | Anterior thigh and medial leg pain | Local Infection at puncture site, severe coagulopathy | Positioning, interference with femoral venous and/or femoral arterial catheters |
| Sciatic | Posterior thigh and leg pain below the knee except for the medial aspect of the leg (LE surgery) | Local infection at puncture site, severe coagulopathy | Positioning |
| Paravertebral | Unilateral chest or abdominal pain (breast surgery, VATS, inguinal hernia repair, chest tube placement) | Severe coagulopathy, untreated contralateral pneumothorax | Positioning |
| Intercostal | Unilateral chest pain, chest tube placement | Severe coagulopathy, Untreated contralateral pneumothorax | Positioning, |



Is it possible to perform the peripheral nerve block and/or placement of a catheter in the presence of central lines and/or tracheostomy sites? Is there an increased risk of infection at that site? Will it be difficult to maintain the catheter site?

Placement may be complicated by the presence of anasarca. Are there skin lesions suggestive of infection? Needle depth may be increased and an ultrasound-guided technique should be used.

Remember also that testing for inadvertent vascular injection of local anesthetics may be complicated by concurrent medications. The sensitivity of a test dose of local anesthetic with epinephrine will be reduced in the setting of β-blockade, α-agonists, and other medications administered to the ICU patient. Similarly, the administration of sedative and analgesic medications will impair the ability of the patient to report symptoms of local anesthetic vascular injection. There may be no change in HR and little change in blood pressure. It may be prudent to monitor for signs of T wave elevation. T wave elevation may result from inadvertent injection of local anesthetic and/or epinephrine. T wave elevation has been reported to occur following rapid inadvertent injection of bupivacaine in an animal model (Table 184.1).

## TAKE HOME POINTS

- Regional anesthesia in the ICU is underutilized, we believe.
- Multiple peripheral nerve blocks may have applicability for ICU patients.
- Regional anesthesia may help decrease ICU delirium by decreasing the need for benzodiazepines, opiates, and other sedating medications.
- Reduction in sympathetic tone may also be beneficial to ICU patients by decreasing ileus.
- Paravertebral, intercoastal, and epidural blocks may help chest trauma patients and other ventilated patients.
- Peripheral blocks may be very beneficial for ICU patients who have sustained extremity trauma such as fractures or burns. Several years ago, one of the editors was herself an ICU patient due to necrotizing fasciitis. She asked the surgical team to heavily infiltrate the wounds and packing with chloroprocaine before changing the dressing of the vacuum-assisted wound device. This “splash block” made a world of difference in the pain associated with pulling the dressing off a very large granulating wound. A more recent study used the same general principle and demonstrated efficacy with retrograde infusion of lidocaine through the vacuum tubing prior to manipulation of the vacuum-assisted device.
- Sepsis, coagulation status, and fluid status must be **carefully considered** before utilizing regional anesthesia techniques in the ICU.
- The protocol for test doses may have to be modified.
- Should always be vigilant when performing regional anesthesia in the ICU.

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## SECTION IX

# PEDIATRIC ANESTHESIA

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# Introduction

Kirk Lalwani, MD FRCA MCR

"A person's a person, no matter how small."
Horton the Elephant, in Horton Hears a Who!
— Dr. Seuss

The essence of anesthesia care for infants and children is captured by one phrase: attention to detail. Gestational age, postmenstrual age, prenatal history, weight, drug dosage, tube size, tube depth, leak pressure, airway pressure, tidal volume, vascular access, nerve localization, line protection, fluids, extravasation, blood glucose, temperature, vital signs, pressure ulcers, positioning, respiratory tract infections, family preparation, patient anxiety, the list goes on and on. Remember that each and every one of these and other details can have a profound impact on the intraoperative course and the postoperative outcome. It could mean the difference between you having to explain an avoidable complication to a distraught family, or feeling privileged to have had the opportunity to successfully care for one of your most vulnerable patients. Residents on their first pediatric rotation often express how after months of adult anesthesia, they find themselves having to think about everything they do before they do it, notably, calculating drug doses. I respond by assuring them that learning to take care of children will make them better adult anesthesiologists, as they will pay greater attention to detail and think about their actions in advance.

In pediatric anesthesia, as in adult anesthesia, it often helps to apply "Golden Rule No. 1" to your decision making: if this was your child or the child of a family member, would you want the anesthesiologist to do that? If you cannot definitively answer with a resounding "Yes," then perhaps you should reevaluate your plan. Similarly, apply "Golden Rule No. 2" if your options remain ambiguous: would you be comfortable explaining your course of action to a room full of your superiors, peers, and trainees at the weekly Morbidity and Mortality conference? If you find yourself squirming at the thought of explaining your rationale (since we all squirm at the thought of presenting at M&M!), then perhaps you should rethink your decision. These simple heuristic tools can

bring clarity to a dilemma that may seem obscured by other considerations related to comorbidities, efficiency, urgency, and expediency.

This section includes many of the pediatric chapters from the first edition, as well as a number of new chapters. You will find words of wisdom from many talented practitioners who show us the nuances of obesity, muscle disease, anesthetic neurotoxicity, pediatric sedation, congenital heart disease, pain management, mission trips, and ethical issues, to name a few. We hope you enjoy them and learn some tips and tricks that will make a difference to your practice, and most importantly, to your patients. Ultimately, that is what it's all about.

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# Assent, Consent, and Refusal: Informed Consent and Decision-Making for Adult and Pediatric Patients

Berklee Robins, MD MA

Contemporary bioethics is in large part based on four primary, equally weighted principles: autonomy, beneficence, nonmaleficence, and justice. As physicians we are well aware of our obligation to respect our patients' preferences (autonomy), do good (beneficence), avoid harm (nonmaleficence), and treat similar patients similarly (justice). The anesthesiologist has a responsibility to obtain informed consent from his patient prior to the administration of an anesthetic. This obligation is derived from both case law (Schloendorf vs. Society of New York Hospital, 1914) and the ethical principle of respect for autonomy. However, sometimes obtaining informed consent can be challenging. The other principles may conflict with patient autonomy, causing an ethical dilemma, such as when a patient refuses potentially helpful medical intervention. When our adult patients lack decision-making capacity (DMC), obtaining consent can be problematic. Pediatric patients present yet a different set of challenges when obtaining informed consent.

## Informed Consent

Informed consent is usually documented following a "PARQ." This useful acronym reminds anesthesiologists to discuss the **procedure** (the anesthetic plan), **alternatives, risks,** and answer the patient's **questions.** Informed consent requires that the patient's choice be autonomous. Choices that are autonomous are marked by intention, understanding, and lack of undue influence (coercion, manipulation, or threat). Only when these conditions are met is consent truly informed and valid. This is the manifestation of shared decision-making between a physician and patient, a hallmark of the modern doctor–patient relationship. The obligation is to secure the patient's understanding, agreement, and permission. This can be documented in writing by having the patient sign a form, or noted in the medical record by the physician after verbal consent, depending on law, policy, or local practice. In either case the process is more

important than the documentation per se. Exceptions to obtaining informed consent include presumed consent in an emergency, voluntary waiver of consent, or in extremely rare cases, therapeutic privilege (when disclosure of information would be harmful to the patient).

## Decision-Making Capacity and Competency

The ability to give informed consent rests on the notion of adequate DMC. DMC is situational and dynamic, meaning there can be DMC for some decisions (what a patient wants for breakfast) but not other decisions that are more complex (should the patient chose chemotherapy and/or radiation after surgery for a potentially life threatening cancer). To have DMC, a patient must appreciate the medical situation, understand the relevant information that is provided to him, and comprehend the consequences of each option. This requires an ability to manipulate information rationally, reason through the process, and communicate a choice. Importantly, a patient's decision not to follow the recommended plan does not necessarily mean that he lacks DMC.

**Competency is often confused with capacity.** In the past, the two words have been used interchangeably. Currently we recognize the importance of distinguishing between them. Competency is a legal term, differing from capacity, which is a medical term. When a judge determines that a patient lacks competence, the patient is no longer able to consent on his own behalf. The determination of incompetence is a relatively infrequent event, as it requires significant legal effort. In most cases when a patient lacks DMC, hospitals and physicians recognize the obvious surrogate(s) as speaking for a patient. Their decisions usually go unchallenged, unless they appear to depart markedly from a reasonable interpretation of the patient's best interests, making the declaration of incompetence (as in the case of a patient with severe dementia) unnecessary.

## When a Patient Lacks DMC

When a patient lacks DMC, and is therefore unable to speak for himself, a surrogate will be called upon to make medical decisions. The patient may simply be unable to communicate his wishes (e.g., if sedated). In other cases, the patient may have lost DMC, either temporarily (e.g., delirium), or permanently (e.g., progressive dementia). Sometimes DMC was never present, such as in young children and adults with severe developmental delay. The designated surrogate may be the legal guardian, someone previously appointed by the patient when he had DMC, or a friend or family member. The "next of kin" (as defined by law or hospital policy) is usually the best option if no other surrogate has been named. In rare cases, the courts will appoint a guardian ad litem if no family can be identified, or there is a conflict among interested parties. This is generally an option of last resort.

## The Role of the Surrogate

When a surrogate is asked to assist in medical decision-making, he or she assumes the responsibility to aid physicians with the determination of what the patient would want if he could state his preferences. This may include decisions relating to medical options, surgery, or end-of-life care. When these preferences are known, this is referred to as "substituted judgment." Sometimes the patient has recorded these desires in writing. An advance directive, or other document, such as durable power of attorney for health care (DPOAHC) which names a health care representative, or physician's order for life-sustaining treatment (POLST) convey at least some of the patient's wishes. In other cases, those who know the patient well may have had discussions with him and can offer this information as an indication of what the patient would want. The legal system has consistently recognized such evidence when it is clear and convincing. It is imperative that the surrogate's decision be made based on what the patient would want, not what the surrogate would choose for himself in that particular situation.

Unfortunately, we are often left without an explicit idea of what choice the patient would make. Ethical decisions can be challenging and complex when the patient's preferences are not known. The wishes may not be known because the patient never expressed them. In others cases, they cannot be known, such as for a young child or an adult with severe developmental delay. A surrogate is then asked to make decisions based on the "best interests" of the patient. The best interests standard directs the surrogate to consider, in the absence of any reliable evidence of the patient's own preferences, how a reasonable person, in a situation similar to the patient, would balance the likely benefits and burdens of the treatments being considered. This may be a difficult job for the surrogate, especially in the case of differing preferences, religious, beliefs, or cultural values.

## The Consent Process for Minors

Children are generally assumed to lack complete DMC. There are both cognitive/developmental and legal considerations. The age of legal majority varies from state to state. Minors are not legally able to provide consent, because they are not legally competent to authorize medical intervention, just as they are not able to enter into legally binding contracts. Exceptions do exist, such as emancipated minors and mature minors. Emancipated minors have not reached the age of legal majority, but are recognized as competent in the eyes of the law, based on criteria such as military service, marriage, or financial and other evidence of self-supporting independence. The legal designation of a child as a mature minor occurs when a judge awards the child (who is often near the age of majority and is able to demonstrate sufficient maturity and DMC) the legal authority to consent. Both of these situations are relatively infrequent.

Therefore, parents are usually asked to consent for their child. Traditionally they are given a wide range of decision-making authority as the child's surrogates.

Based on their biologic immaturity, infants and young children lack DMC. As a child ages, he is able to understand increasingly complex situations. By the upper single digits, many children are able to voice preferences, even though they do not have the same DMC as older children or adults. By the mid-teenage years, children are thought to have near-adult DMC, at least in some situations. It is important to remember that these ages are approximations, with DMC developing at different ages (or not at all) for a variety of reasons. Hence, assignment of partial or complete DMC must be assessed individually.

## Assent, Consent, and Refusal for Pediatric Patients

Assent (agreement) is a concept that is often helpful in involving pediatric patients in the anesthetic plan. Following a developmentally appropriate discussion, a child may accept the medical plan, essentially agreeing to proceed. As the child's cognitive abilities mature, DMC may allow the child to take a greater role in the PARQ and assent can begin to resemble consent (autonomous choice). However, true legal consent (permission) cannot be obtained until the patient has reached the legal age of majority. Until that age is reached, parents are generally asked to provide formal consent following the PARQ. The assumption is that parents will act in the best interests of their child, as described previously.

Refusal of treatment is a concept related to consent, but in the negative. **Adults with DMC always have the right to refuse treatment, even when it is not in their medical best interest.** Courts have repeatedly upheld this right; it is perhaps the ultimate respect for autonomy. Like consent, refusal of treatment is more complex in the pediatric population. Minors are often allowed to consent for different types of treatments at different ages. Consent for reproductive health issues such as contraception may be permitted at a younger age, while other medical issues, such as consent for surgery, may not be allowed until the child is older. In some states a child does not have the right to refuse treatment until he reaches yet a different age. The practical implications of forcing an older teenager to undergo a treatment he does not agree to can be quite problematic, even if his parents and doctors recommend it. It is important for the anesthesiologist to remember that long-term family relationships extend beyond a particular decision, and that the parent–child relationship is dynamic, especially throughout a chronic medical condition. Facilitation of a decision that respects autonomy and supports the family is the goal.

Parents do not have an obligation to agree to a specific anesthetic plan or other medical treatment for their child. In most cases, the anesthesiologist should accept the

autonomous choice of a patient and his parents, even if it is not what the anesthesiologist recommends or would choose for himself. While an anesthesiologist is under no obligation to provide care that is not medically indicated (even if requested), and should not offer a plan that is not medically sound, patients and parents do have the right to choose among the various reasonable alternatives (the "A" of PARQ) presented to them.

There are limits to parental rights to decide what is best for their child. In general, if the choice parents make appears not to be in their child's best interest, further exploration of the decision is warranted. The level of scrutiny should be in proportion to the consequences of the decision. Choices with few or no serious ramifications generally go unquestioned, falling more in the category of preferences. Refusals of interventions with greater risks and/or consequences require greater investigation. In the most extreme situations, when the parents' decision or behavior is seen as not in a child's best interest, and potentially harmful or neglectful, it is necessary to challenge the parents' decision. Social workers may be of great assistance, involving child protective services if needed, and in extreme cases, seeking judicial intervention. This may result in the child being placed in the custody of the state or having a guardian ad litem appointed. Distinguishing between decisions that a provider disagrees with, and those which meet the threshold of harm or neglect, may be difficult.

## Resolution and Assistance

Respect for a patient's autonomy is both a crucial legal and ethical obligation. Informed consent in the patient with DMC is the practical implementation of this principle. Anesthesia providers should have a basic understanding of the criteria for DMC. If they have concerns that DMC is absent in an adult, they should confer with the other clinicians involved in the patient's care to determine if DMC is present at a level adequate to consent for surgery or other planned intervention. The primary care provider who knows the patient best may be very helpful in determining DMC. Hospitals often provide policy or guidelines that aid in assessing and documenting the presence or absence of DMC. Psychiatry or ethics consultation may be indicated if it is unclear whether DMC is present or there is disagreement among family or providers. In the case of pediatric patients, one must combine respect for the parents' right to make decisions in the best interests of their child with developmentally appropriate assent from the patient. Sometimes children and their parents are in disagreement about decisions. Primary care physicians who know the family, social workers, chaplains, and child-life specialists may all be useful in exploring the issues that make conversations between providers and patients and their families challenging. The ultimate goal is to respect the preferences and decisions of the patient and parents whenever possible.

When endorsed values are honored, physicians will have met both the legal and ethical obligations to obtain informed consent.

## TAKE HOME POINTS

- Obtaining valid consent is critically important to the proper, ethical, and legal delivery of medical care.
- We recommend the PARQ model when approaching the issues of consent.
- Remember that competency denotes a legal status and decision-making capacity denotes a medical status.
- Decision-making capacity is dynamic and situational—a patient can have capacity to consent for surgery but not for anesthesia or capacity to consent for one procedure or treatment but not another.
- A competent adult with decision-making capacity has the absolute right to refuse care, even if it is in their own best interest.
- Unless a child is under a legally emancipated status, they can give assent but not consent.
- Know your hospital's "next-of-kin" hierarchy and remember that sometimes the "kin" can be somebody who is unrelated by blood.
- This part of your medical practice deserves your utmost communication and empathy skills. Never, NEVER get into harsh disagreement with a patient or family over these issues. Never show the slightest degree of impatience or negative judgment toward the patient, the family, or the surrogate. If you are in a difficult situation, involve support staff including the ethics people, the psychiatrists, the social workers, the surgeons, and the people in your own supervisory chain as early as possible.

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# NPO Guidelines Made Easy—Always Maintain a Firm Hold on Current Principles, Best Practices, and Your Own Common Sense

Gregory Maves, MD and Elizabeth Ross, MD

Preoperative fasting guidelines and orders have long confused and upset patients and caused trouble for perioperative providers. In making decisions on whether an appropriate nothing per os (NPO) status has been maintained, the anesthesiologist is always balancing the risks of a full stomach and pulmonary aspiration with the threat of prolonged fasting, dehydration, perturbations in the autonomic system, and hypoglycemia. While also considering the probability of irritable children, disgruntled parents, and a constantly evolving operating room schedule! The situation is not helped by the fact that, in the past, pediatric NPO and fasting guidelines were variable, based on individual expert opinions, and too long.

Let us take a moment to consider the common-sense approach to pediatric preoperative NPO status. **First, while many studies have suggested that the risk of aspiration is higher in children than adults, large retrospective studies have shown that perioperative pulmonary aspiration in pediatric patients is rare, and significant morbidity resulting from aspiration is even less common.** Second, remember that we ourselves frequently take completely NPO children and render them **not** completely NPO. This is because pediatric anesthesiologists generally **do accept** the risk of the ingestion of premedications such as midazolam just prior to induction of anesthesia due to the other desirable attributes of these drugs. So use this commonsense when you are faced with a child who has chewed gum or sucked on a lollipop. Third, there continues to be a lot of thought and ongoing research into optimal NPO status, as there should be. Fourth, the general trend has consistently been toward the liberalization of preoperative fasting requirements.

Recent studies in adult populations have encouraged consumption of a carbohydrate drink up to 2 hours prior to surgery. Consumption of these drinks has been associated with improved insulin sensitivity postoperatively, faster return of bowel function, and increased patient satisfaction. This has resulted in alteration and optimization of formal

preoperative fasting guidelines, including those at the editors' own institutions. Similar studies in children are underway and may be an area for change in future iterations of the ASA guidelines.

In 2011, the American Society of Anesthesiologists published revised pediatric Practice Guidelines for Preoperative Fasting and the Use of Pharmacologic Agents to Reduce the Risk of Pulmonary Aspiration. These guidelines provide clinical recommendations based on a review of current literature, a large survey of physicians, and a consensus among anesthesiologists within the Task Force on Preoperative Fasting.

The task force's guidelines are intended for healthy patients scheduled for elective procedures and provide appropriate fasting intervals for each type of ingested material. According to the guidelines, clear liquids may be given up to 2 hours prior to a procedure. Clear liquids frequently given to pediatric patients include water, fruit juices without pulp, and oral rehydration solution. The recommended fasting interval for breast milk is 4 hours and 6 hours for formula, nonhuman milk, and light, dry solids. Finally, fasting times for foods considered to be fried or high in fat should be at least 8 hours as they may prolong gastric emptying time. These NPO recommendations are most easily remembered as the "2, 4, 6 rule." **Two hours for clears, four hours for breast milk, and six hours for formula, non-human milk, and light solids.**

**Summary Table of ASA Guidelines for Types of Foods and Their Corresponding NPO Requirements**

| Type of Food | Time Until NPO (hr) | Examples |
|---|---|---|
| Clear liquids | 2 | Water, juice without pulp, Gatorade, soda |
| Breast milk | 4 | Breast milk |
| Solids/light meal | 6 | Infant formula, cereals, fruits, vegetables, nonhuman milk |
| Fat containing foods | 8 | Meats, dairy containing foods, fried foods, large meals |

As part of their guidelines, the task force emphasized the importance of a preoperative evaluation of each patient and recognition of comorbidities that may increase the risk of pulmonary aspiration. Gastroesophageal reflux, ileus, and bowel obstruction are prevalent among the pediatric surgical population and warrant individualized perioperative care based on the severity of the patient's condition.

No formal guidelines exist for preoperative medications, and decisions must be made on an individual basis. Pediatric patients requiring daily medications can generally be given these medications on the morning of surgery with a small amount of water. A prospective study in pediatric surgical patients showed no significant change in gastric pH or residual volume in those given oral midazolam mixed with 5 mL of water.

Special consideration must be given to medications that involve the administration of a larger volume of liquid. The Task Force on Preoperative Fasting does not recommend the routine preoperative use of gastrointestinal stimulants, histamine-2 receptor antagonists, antacids, or antiemetics due to insufficient evidence to support reduced pulmonary aspiration. The guidelines instead emphasize the importance of the fasting intervals for the specific types of ingested liquids and solids. An exception to this arises for the patients for whom "premedications" means parenteral tube feeds. If the patient will be coming to and leaving the OR with a protected airway, such as an endotracheal tube or surgical airway, it is the general practice of the editors to maintain the tube feeds until just before the patient goes to the OR. Otherwise, it is hard to maintain the patient's nutritional status, particularly if the patient is undergoing daily procedures.

The senior editors of this book are frequently asked about "bending" NPO rules for pediatric patients. As we state above, every practitioner must keep his or her patient safe, using the available literature, published guidelines, clinical expertise, and common sense. If the question is a matter of gum-chewing, we generally believe the data support not delaying surgery. Otherwise, the issue is not really about bending the NPO guidelines, it is really about using good judgment and consensus opinion about how emergent the case is. If the request is one that makes the anesthesia provider uncomfortable when it is fully documented in the chart—that is, if the fasting violations are fully and accurately documented and the case remains fully elective, then do not do the case. As collaboratively and politely as you can, say no. But if you can reasonably meet the threshold that all parts of the case and chart match each other—your note documenting the rationale for proceeding with the case matches the clinical urgency of the surgeons—**and they will actually document this clinical urgency**—then it is reasonable to proceed, using careful and appropriate techniques, such as a rapid-sequence induction.

Unfortunately, despite nearly two decades of standardized NPO guidelines for children, actual fasting times in children continue to be excessive with corresponding negative feelings of hunger and thirst. Unfortunately, many barriers prevent adherence to the guidelines. A combination of inadequate perioperative team education and poor communication between providers and families likely contributes to the prolonged fasting times seen in clinical practice. Varying strategies exist for improvement

including scheduled oral fluid orders prior to surgery, parental education pamphlets, and continued education of clinical providers. By balancing clinical factors, pediatric patients may be safely anesthetized at the time of their procedure while minimizing the number of irritable children and frustrated parents in the surgical waiting room.

## TAKE HOME POINTS

- Remember—two, four, six, eight! Two hours for clear liquids including clear juices, Gatorade, and soda. Four hours for breast milk. Six hours for light solids including crackers, biscuits, cookies, fruits, vegetables, and other types of milk. Eight hours for meat, heavier dairy foods such as ice cream, pizza, mac-and-cheese, and fried foods.
- Recognize that the NPO guidelines for "milk" and "dairy" is the place where there is a little bit of confusion, since breast milk is allowed at 4 hours, but all other kinds of milk are only allowed at 6 hours prior to the operative case, and nonmilk dairy is allowed only at 8 hours prior to the case.
- If you are confused or uncertain about what is a "light" solid meal and what is a "heavy" solid meal, try framing the decision in your mind in terms of adult "strict diet" food. A small plate of linguini with olive oil and mushrooms or tomato sauce is "diet" whereas a bowl of lobster mac-and-cheese clearly is not, and so forth. Also, ask not only **what** the patient had to eat, but also **how much**.
- Eggs and butter should generally be considered with dairy and cheese as heavier solids. Again, however the amount of these foods that were consumed and common sense are important. A couple of spoonfuls of a soft-boiled or scrambled egg or a tiny amount of margarine on a cracker are probably okay to be considered light solids. A three-egg Western omelet is not.
- Make all parts of the case match each other. There are many factors that go into determining the surgical urgency of a case and this is generally not a call that should be made by the anesthesiologists. Just make sure that if the surgeons are willing to make a statement revising the surgical urgency to you and the parents, they have made the same statement in the electronic record, before you start the case.
- Chewing gum in the 2 hours before surgery is probably okay. The same with a hard candy like a Life-Saver or a lollipop– remember to put the lollipop or Life-Saver in the context of the thousands of five milliliter aliquots of midazolam that are syringed into the mouths of toddlers and older children every day in same-day surgery units. A bag of tootsie-rolls or a candy bar is not okay.
- Every single patient you care for will have a preoperative NPO status. Follow the literature on this closely and keep abreast of the latest studies. Don't hang onto NPO standards and guidelines and biases from the past or from your training years. Remember that preoperative fasting is something that has been psychologically and

physiologically stressful for millions of patients down through the years. Welcome and quickly adopt the updated research and guidelines that can make the perioperative period safer and more comfortable for your patients.

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# Aspiration and Food Injury—Or When Not to Extubate Deep

Marion Bussay, MD and Leelach Rothschild, MD

Pulmonary aspiration of gastric contents is a rare but feared complication of anesthesia. First described in obstetrical cases by Mendelson in 1946, it is still one of the most common causes of morbidity and mortality secondary to anesthesia. Many precautions are often taken to avoid aspiration, only some of which are backed by research. Even widely accepted risk factors for aspiration such as trauma and gastric pH are now being questioned by new data. In this chapter we will review risk factors and precautions for aspiration in light of developing information.

## Risk Factors

### Gastric Volume and pH

A gastric fluid volume more than 0.4 mL/kg and a pH of less than 2.5 are often taught to be indicators of aspiration risk. An article by Roberts and Shirley in 1974 advocated these arbitrary parameters and they became commonly accepted in clinical practice. However, recent studies show that gastric volume is often greater than 0.4 mL/kg and pH less than 2.5 in patients presenting for elective surgery, yet the incidence of aspiration remains low. Also, contemporary animal studies suggest that 0.8 mL/kg poured directly into the trachea is needed to produce aspiration pneumonitis. Although acidity of gastric contents does affect severity of lung damage, alteration of gastric pH pharmacologically has not shown to be conclusively beneficial in the event of aspiration.

### Opioids

Opioids inhibit gastric emptying and reduce lower esophageal sphincter tone. This may lead to an increased risk of aspiration. The use of opioids following trauma may be useful for identifying patients at risk for aspiration.

### Nausea and Vomiting

Nausea and vomiting are often used as markers for increased risk of aspiration. However, currently no definitive evidence supports or refutes this claim. Presence of vomiting may suggest that gastric contents are present and have the potential to be aspirated.

## Trauma

It is commonly believed that trauma slows gastric emptying and thus increases risk of aspiration. Bricker et al. showed that 62% of children presenting after trauma had gastric volumes greater than 0.4 mL/kg and concluded that they were at increased risk for aspiration. However, this assumption is based on the recently questioned parameter of gastric volume as a predictor of aspiration. In contrast, Steedman et al. found that gastric volume was the same in post-orthopedic fracture patients when they presented for surgery and when they came for outpatient follow-up. Current evidence is lacking to state whether trauma itself increases the risk of aspiration, but many factors associated with trauma such as severe pain and opioids may delay gastric emptying and predispose to aspiration.

## Precautions

### Time

During normal conditions, gastric contents decrease exponentially with time in accordance to the size and contents of ingested food. Current guidelines from the American Society of Anesthesiologists include fasting for 8 hours after a fried or fatty meal, 6 hours after a light meal or formula, 4 hours after breast milk, and 2 hours after clear liquids. However, during trauma or stress, the time needed for gastric emptying is unknown. Some institutions follow a guideline of fasting for 4 to 6 hours for trauma cases if possible, while others proceed with the case as gastric contents are unpredictable. Either way, the potential for a full stomach must be considered in the anesthetic plan.

## Cricoid Pressure

Cricoid pressure is a much-debated practice that many clinicians currently follow. Theoretically, when cricoid pressure is properly applied, the esophagus is compressed by the trachea and decreases the risk of aspiration. However, properly administered cricoid pressure is difficult to perform and it is unclear whether it is even efficacious when performed correctly because studies utilizing magnetic resonance (MR) imaging show lateral displacement of the esophagus with cricoid pressure. It can also distort the airway making intubation more difficult and decrease lower and upper esophageal sphincter tone. For these reasons, some clinicians advocate for better training on cricoid

pressure application while others question its continued role as a standard of care during rapid sequence inductions.

## Pharmacotherapy

There are currently no data that show decreased risk of aspiration after the use of antacids, $H_2$ blockers, proton pump inhibitors, or prokinetic agents. Most of the studies suggest that these agents decrease gastric fluid volume and increase pH, but these markers are being questioned as appropriate measures of aspiration risk.

## IV Placement Prior to Induction

For trauma and emergency cases, most children will come to the operating room with an IV. If an IV is not present, it is prudent to consider placement prior to induction to facilitate the use of a rapid sequence induction.

### TAKE HOME POINTS

- Although trauma itself has not been proven to increase risk of aspiration, associated factors can lead to decreased gastric emptying.
- The most commonly used parameters by anesthesiologists to predict aspiration risk in pediatric trauma cases include the eating to injury time (or food–injury interval), use of opioids, the presence of pain, eating to operation time, and the presence of vomiting.
- The length of time needed for adequate gastric emptying to decrease the risk of aspiration is unpredictable when trauma is involved. Some clinicians will wait 4 to 6 hours before proceeding while other clinicians will proceed assuming a full stomach. The urgency of the procedure will also dictate whether it is prudent to wait or to proceed while acknowledging the perhaps higher risk of aspiration.

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# Don’t Underestimate the Power of Distraction During Separation and Induction of Anesthesia in Kids

Emily Olsen, MD and Jorge Alberto Pineda Jr, MD

A 4-year-old boy presents for tonsillectomy to address his obstructive sleep apnea. He has a history of a paradoxical reaction to midazolam given during a previous dental procedure. He also has a history of emergence delirium after previous ear tube placement. You go to meet him and his family in the preoperative area. His dad is tending to his younger brother who is upset and audibly crying. The patient is sitting in his mother’s lap attentively watching her check her email on her smartphone. The preop nurse stops you before you approach the family and reminds you that you need to give the premed now or risk not making it to the operating room on time.

## No Midazolam?

First, understand and be prepared for the fact that **midazolam is not always the answer**!

As any experienced anesthesia provider can tell you, midazolam is not always the answer when it comes to preop anxiolysis, especially in the pediatric setting. As with any medicine or technique, it comes both with pros and cons. When midazolam works, it works very well. However, as in the clinical vignette, midazolam can be associated with a paradoxical response or otherwise may not provide the intended anxiolysis.

## So …. Back to Basics!

Why do we aim to provide anxiolysis for induction of anesthesia in pediatric patients? Does it really matter past the fact that it makes the experience easier for all involved? Yes—it does. Several well-designed studies have shown an association between high preop anxiety and increased undesirable postop variables including pain, increased analgesia requirements, anxiety, emergence delirium, and behavior and sleep

disturbances which may last for weeks. Also, less perioperative anxiety is associated with better patient, family, and provider satisfaction.

## Introduction to Distraction Techniques

What else can the provider do to provide anxiolysis in the preop setting? Parental presence at induction of anesthesia is one well-established technique. It is discussed in detail elsewhere, so we will not go into detail here. Distraction techniques have been used and perfected in multiple healthcare settings. For example, much of the early literature describes successful use of distraction to decrease the pain and anxiety associated with childhood immunizations and dental procedures.

Naturally, such techniques have been translated to the perioperative realm. This might be as simple as telling a story or engaging the patient in conversation while taking the child from the parents and proceeding with induction of anesthesia. Other techniques involve different personnel like child-life specialists or clowns (with some reports of anesthesia providers dressing as clowns). Various props can be helpful as well (e.g., stuffed animals, stickers, or other toys).

The pediatric hospital design often helps promote distraction techniques; for example, our hospital has a series of butterflies painted on the ceiling and silly pictures of various animals on the walls along the route to the main operating rooms. Our operating rooms also have television screens, so we can play cartoons or other popular movies to aid in distraction during induction. Some institutions incorporate the use of video glasses, which enable children to watch and listen to cartoons and movies, and can be used through the completion of inhaled induction.

Similarly, with continued advances in mobile technology, we now have another versatile tool in our distraction toolbox: smartphones and other mobile electronics. Surely many families discovered that smartphones or portable DVD players are excellent distraction methods well before they entered the medical environment. The nice thing about emerging smartphone technology is the growth in easily accessible games appropriate for various developmental levels. For example, a touch-screen game that plays sounds or creates different visual effects with each touch would be more appropriate for a toddler. On the other hand, a puzzle game or racing game would involve higher-level reasoning and be more appropriate for the older child or teenager.

### TAKE HOME POINTS

- Preop anxiety is associated with poor postop outcomes (pain, anxiety, emergence delirium, behavioral disturbances).
- -The goal of distraction is to engage your patients in a way that fully immerses their

mind in something apart from the often anxiety-provoking perioperative experience.

- Be flexible. Think on your toes! Customize each experience such that it is developmentally appropriate for each child and family. Do not be afraid to consult with the parents as to what will work with their child and what will not.
- Talk with and learn from more experienced clinicians. Every operating room that provides care for children will have someone who is especially good at the art of distraction. Find that person and watch what they do and do not do.

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# Parental Presence on Induction—It's Your Call and How to Do It

Nicole Conrad, MD and Kimberly Blasius, MD

Preoperative anxiety is common in pediatric surgical patients, with up to 60% of children reporting a significant amount of anxiety in the perioperative period. Anxiety and preoperative stress are associated with negative perioperative outcomes such as emergence delirium, sleep disturbances, and maladaptive behaviors. Parental anxiety has also been associated with negative postoperative outcomes such as poor postoperative pain control and behavioral changes. Optimizing the perioperative environment for the family is an important and challenging component to pediatric anesthesia care.

Reduction of anxiety in pediatric surgical patients is a common concern for the anesthesiologist. Pharmacologic anxiolysis is often available and effective but there are risks with sedating medications such as respiratory depression and prolonged emergence as well as complications such as allergy or patient and/or parental refusal. Alternatives to anxiolytic medications have been examined, for example parental presence, video distraction, and clown doctors.

In this chapter, we review current literature on parental presence during induction of anesthesia. A 2015 Cochrane review describes nonpharmacologic interventions to improve induction compliance in pediatric patients. The review concluded that literature to date does not indicate that parental presence improves pediatric patient anxiety or cooperation with induction. In addition, parental presence does not significantly prevent emergence delirium or improve parental satisfaction or shorten time taken for induction. Despite this literature, parental presence is still relatively common in pediatric anesthesia practice.

The potential benefits of parental presence during induction of anesthesia are determined by factors such as the child's age, activity level, overall temperament, as well as the baseline anxiety level of the parent. The anesthesiologist must evaluate each family on a case-by-case basis in the preoperative area carefully weighing the risks and benefits. The decision should be made based upon optimization of patient safety versus

the expectations or desires of the parents.

If the anesthesiologist chooses to allow parental presence there should be a thorough evaluation and proper preparation of the parent preoperatively. Parental anxiety can negatively contribute to induction compliance and worsen the experience for the patient. It is important to evaluate the parent's level of anxiety to determine if they will be effective and not a hindrance to the patient's anxiety. Also, it is not advisable to encourage a parent to be present on induction if they are hesitant. **It is imperative to educate participating parents about the environment of the operating room and the process of anesthetic induction.** This will improve the overall experience as well as prevent complications. A recent case report highlights the rare but potential catastrophic complication with parental presence in which the parent removed a child from monitoring during induction and tried to take the child from the operating room.

It is beneficial to institute a hospital policy regarding parental presence that is well known by the surgical team and can be communicated to parents during preoperative workup such as at a clinic visit. The policy can include a statement that the anesthesia provider on the day of surgery has authority for making the ultimate decision of whether to allow parental presence. This will facilitate realistic expectations for the parents and surgery staff on the day of surgery. At some institutions there are rules for specific ages of children or if patients already have an intravenous (IV) line in place. Separation anxiety most commonly begins past the age of 8 to 9 months so it is unlikely that a patient younger than this will benefit from parental presence. If an IV is already in place there are additional options for anxiolytic medications and IV induction is often less traumatic than a mask induction. For a successful experience, the anesthesiologist should communicate with parents early to prepare for potential parental presence and the operating room staff should be organized and skilled on the inclusion of parents in the child's anesthetic.

Parents may be prepared by explaining that the agitation of the second stage of anesthesia can include potentially noisy, obstructed breathing, necessity for head repositioning, and the disappearance of the "beeps" of the pulse oximeter which is most often as a result of movement or second stage agitation. It is also useful to emphasize that in the event of difficulty, the parent might be asked to leave and wait outside so providers can devote their full attention to their child.

Although literature has shown that parental presence alone has not been effective at reducing preoperative anxiety in pediatric surgical patients (Manyande et al.), Kain et al. report effective anxiety reduction with a family-based approach to preoperative preparation called ADVANCE. This program utilized a combination of tools such as preoperative education including tour of operating room, video-distraction, and parental presence on induction.

Recent literature has attempted to improve effectiveness of parental presence by implementing interventions directed specifically at parental preparation. In three trials, video preparation for the parent showed no advantages in terms of patient anxiety. A different study looked at the efficacy of preoperative parental acupuncture, which was successful at improving both parental anxiety and children's induction compliance.

In summary, despite limited literature of success in reducing anxiety in pediatric surgical patients, parental presence is still an option for induction of anesthesia. Most commonly this is because a parent is eager to participate and concerned about traumatic separation from their child. It is important to evaluate and prepare the patients thoroughly and maintain final decision-making control over whether or not parental presence would be beneficial. In the future, parental presence may be improved by preoperative interventions such as more extensive education or anxiety relieving measures such as acupuncture.

## TAKE HOME POINTS

- Parental presence has not been proven to be effective at reducing pediatric surgical patient anxiety on induction.
- If parental presence is utilized it is important to prepare parents for the experience of the operating room and explain what to except during induction of anesthesia (including agitation stage).
- Patient safety is the ultimate goal and the decision to allow parental presence is up to the anesthesia provider.
- Parental presence may be beneficial if used in conjunction with other modes of anxiolysis such as video distraction, family based surgery preparation, or parental acupuncture.

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# The Child With a URI

Ann Bailey, MD FAAP

One of the most common dilemmas for the anesthesiologist is deciding whether to anesthetize the child who just recovered from or currently has an upper respiratory tract infection (URI). But really, the first problem is actually to determine if the child has a URI at all. Symptoms may be very similar to other illnesses or allergies. When is a runny nose secondary to a URI, and when is it due to allergic rhinitis? Signs that are associated with a URI include purulent rhinorrhea (that is, "green snot"), fever, sore throat, productive cough, or other lower tract signs such as wheezing or rhonchi. Remember that allergic rhinitis is not associated with fever or productive cough; rhinorrhea is usually clear, and it is often associated with a history of atopy.

The most reliable way to tell the difference between an URI and allergic rhinitis or other benign entities is to get a good history from the parents. If they relate that the child developed symptoms in daycare or from other sick siblings, it is probably a URI. Also, one should suspect that the child has a URI if they tell you that their child's symptoms are new and not a routine occurrence. There are, however, some children who "keep a cold." In one study the probability of a URI in a child younger than 3 years, in daycare, with parents who smoke in crowded house was 0.61 in any given 2-week period!

The second problem is determining whether the URI will impact on the child's anesthetic course. Early studies demonstrated that what is thought to be purely an upper respiratory tract infection might also involve the lower airways with decreased $FEV_1$, FVC, VC, and with increased reactivity for up to 6 weeks after the infection. In viral airway infections, much of the bronchial hyperreactivity is vagally mediated. It is thought that some viruses produce a viral neuraminidase which decreases the function of $M_2$ muscarinic receptors. As a result there is increased release of acetylcholine in virus infected airways. There may also be a decrease in airway neutral endopeptidase activity which is an enzyme responsible for inactivating tachykinins. These effects render the lower airways are more susceptible to smooth muscle contraction, hence increased airway reactivity.

The typical URI also is associated with more airway secretions. The combination of

increased secretions with increased reactivity leads to the adverse events often quoted in clinical studies of anesthetized children with URIs: coughing, breath-holding, laryngospasm, bronchospasm, and episodes of desaturations.

The next question then becomes, which cases should be cancelled to avoid serious complications in the child with a URI? Children who present for an elective procedure with moderate to severe signs and symptoms of fever, myalgias, lassitude, wheezing or rhonchi are easily discerned as high risk and therefore delayed. But those who present with mild or recent symptoms are also at risk for adverse events. Tait evaluated over 1,000 children scheduled for elective surgery who were either well, had a recent URI (within 4 weeks) or an active URI. The incidence of adverse respiratory events was greater in the recent and active URI groups compared to the no URI group. Independent risk factors for respiratory complications in those children with a URI were: copious secretions, presence of an endotracheal tube in children less than 5 years, history of prematurity, nasal congestion, paternal smoking, history of reactive airway disease, and airway surgery. The more serious complications of laryngospasm and bronchospasm were not different among the groups. Cohen studied 1280 children with preoperative URIs compared with 20,876 children without URIs and demonstrated that there was an 11-fold increase in the risk of a respiratory complication if the child with a URI required intubation. A more recent study showed that laryngospasm and bronchospasm (the 2 complications most relevant to the anesthesia provider) were most likely with a green runny nose, moist cough, or current fever.

Does the increased risk of adverse respiratory events mean that every child with a current or recent URI should be delayed for at least 4 weeks (6 for lower tract symptoms)? Absolutely not, since the vast majority of children with a URI having an anesthetic will do well especially after 2 weeks. Identifying children with higher risk factors and delaying those surgeries is reasonable. The child with a clear runny nose for 3 days who is otherwise well and who is scheduled for an adenoidectomy will probably do fine. One can improve the likelihood of an uneventful anesthetic by tailoring it to minimize reactivity (Table 191.1). Sevoflurane with its mild airway pungency causes fewer respiratory events when used as a maintenance agent in children with a URI, although the use of propofol for maintenance may decrease reactivity further. In addition, the use of a laryngeal mask airway (LMA) or facemask when feasible will decrease complications. A dose of atropine or glycopyrrolate as both an antisialagogue and a vagolytic agent may decrease risk. Using salbutamol (2.5 to 5 mg) prophylactically may decrease airway complications. In a younger child who will require intubation, one should anticipate a higher incidence of postoperative croup and consider giving dexamethasone intraoperatively. Using topical lidocaine on the vocal cords has not been shown to decrease respiratory complications.

Cancellation of everyone with a recent URI is no longer indicated. With such a small amount of scientific evidence regarding the risks of anesthesia for the child with a URI, clinical experience and common sense must help to determine our course of action.

**Table 191.1 ■ Strategies for Minimizing Risks With a URI**

| |
|---|
| Use of LMA or mask instead of ETT if possible |
| Atropine or glycopyrrolate preoperatively or intraoperatively |
| Use of sevoflurane rather than desflurane or isoflurane |
| Use of propofol for an IV induction; consider IV propofol for maintenance |
| Salbutamol 2.5–5 mg inhalation preoperatively |
| Dexamethasone in a small child who requires intubation |

## TAKE HOME POINTS

- Having a scheduled patient who presents with a history of current or recent URI is a common occurrence for the pediatric anesthesiologist.
- First, determine if it is really a URI and if so, how severe. Look for purulent rhinorrhea, fever, sore throat, productive cough, and lower respiratory tract signs such as wheezing and rhonchi.
- Do not hesitate to delay surgery for a patient who is at higher risk or presents with a toxic appearance.
- Remember though, that even more mild symptoms and/or a more recent presentation can pose a perioperative risk to the patient.
- Minimize airway reactivity with the use of sevoflurane, propofol, LMAs, or even a mask airway.
- Atropine or glycopyrrolate can help as well. Lidocaine administered to the vocal cords has not been shown to have efficacy in the pediatric patient with a URI.
- Vigilance is crucial in these but it is important for beginning and even more experienced practitioners to note that blanket cancellation of every patient with a recent URI is no longer indicated.

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# Accept That You Will Have to Meet the Clinical Challenges of Obesity and Obstructive Sleep Apnea in Your Pediatric Patient Cohort

Natalie R. Barnett, MD and Katharina Beckmann, MD

As with other age groups of patients, obesity is growing to epidemic proportions in children and adolescents. Over the last 20 to 30 years in the United States, there has been a three-fold increase in obesity among children and adolescents (especially in the black and Hispanic populations). Obesity-related comorbidities are rising in this population as the body mass index (BMI) climbs higher and higher leading to a concurrent increase in health care spending.

This chapter aims to provide a review of obesity in pediatrics and its comorbidities with emphasis on obstructive sleep apnea (OSA) along with perioperative anesthetic management strategies for this rising population.

## Definitions and Comorbidities

### BMI

Calculated as weight in kilograms (kg) divided by the square of height in meters ($m^2$). As defined by the Centers for Disease Control and Prevention (CDC), BMI is age and sex specific when in reference to children and adolescents. BMI is often referred to as "BMI-for-age" in these age groups and plotted against CDC BMI-for-Age Growth Charts to yield a percentile ranking. The percentile ranking can then be used to categorize a child as underweight (less than 5th percentile), healthy weight (5th to 85th percentile), overweight (85th to95th percentile) or obese (equal to or greater than the 95th percentile). Along with the American Academy of Pediatrics (AAP), the CDC recommends the use of BMI as a screening tool for overweight/obese children but cannot be used as a diagnostic tool.

### Coronary Artery Disease (CAD)

Obesity in children carries a **nearly 10-fold risk for hypertension.** This risk may be

due to increased sympathetic tone, sodium retention or increased angiotensin system activity. Cholesterol abnormalities are also seen in these patients (usually increased triglycerides and LDL and decreased HDL).

## Diabetes Mellitus, Type 2 (DM)

The diabetes epidemic has occurred in parallel to the obesity epidemic and a 10-fold increase in the diagnosis was seen in the 1980s and 1990s. The diagnosis is made based upon the presence of polyuria/polydipsia and two separate fasting blood glucose levels above 126 mg/dL. In some overweight/obese children, the presentation will be subtle and the diagnosis may go unnoticed so screening in this population is key.

## Mental Health

Overweight/obese children and adolescents are more prone to have depressive symptoms with associated lower self-esteem.

## Metabolic Syndrome

An elevation of any three of the following: blood sugar, waist circumference, lipids, or blood pressure.

## Nonalcoholic Fatty Liver Disease (NAFLD)

A spectrum of liver disorders ranging from steatosis to steatohepatitis to hepatocellular necrosis, fibrosis and cirrhosis. Liver biopsy is required for the diagnosis and staging while serum transaminases can be used for screening in obese children.

## Obstructive Sleep Apnea (OSA)

The most severe form of sleep-disordered breathing during which partial or complete airway obstruction leads to breathing cessation. OSA is four to six times more common in obese children. Presenting signs and symptoms include nocturnal snoring, restlessness, frequent awakening, enuresis, and daytime somnolence. During sleep, children/adolescents with OSA may have oxygen desaturations and hypercapnia.

## Orthopedic Comorbidities

In overweight/obese boys, slipped capital femoral epiphysis is more common and should be suspected in children with hip or referred knee pain. In kids older than 8 years, Blount disease is more common in obese children and presents with bowing of the tibias.

## Pseudotumor Cerebri

Idiopathic elevation of the intracranial pressure (ICP) above 200 mm $H_2O$ on lumbar puncture is known as pseudotumor cerebri. It is a diagnosis of exclusion without any other identifiable cause. Patients will typically present with symptoms such as headache, nausea/vomiting, neck pain, eye pain with extraocular movement, diplopia, tinnitus, and vertigo. Findings on physical exam may include papilledema, nystagmus, visual field deficits, and sixth cranial nerve palsy.

## A Focus on OSA

The prevalence of OSA in children ranges from 1% to 10% and it is the most common indication for tonsillectomy +/– adenoidectomy. It is the most severe form of a spectrum of disorders known as sleep-disordered breathing (disorders ranging from snoring to apnea). OSA is classically characterized by upper airway obstruction during sleep and formally defined by the AAP as a disorder of breathing during sleep associated with prolonged partial upper airway obstruction and/or intermittent complete obstruction that disrupts normal ventilation during sleep and normal sleep patterns with concurrent signs and symptoms characteristic of the disorder (see Table 192.1).

## Diagnosis

Overnight polysomnography is the gold standard for diagnosis of OSA though other modalities of diagnosis such as videotaping, nocturnal pulse oximetry, and daytime nap polysomnography are also used.

**Table 192.1 ■ Signs and Symptoms of Obstructive Sleep Apnea**

| Symptoms | Signs |
|---|---|
| Daytime<br>• Excessive sleepiness<br>• Difficulty waking up & unrefreshed<br>• Behavior problems including hyperactivity, aggression, moodiness, and difficulties at school<br>• Poor appetite and dysphagia | • Growth disturbance (FTT or obesity)<br>• Abnormal tongue position, nasal airway obstruction and other craniofacial abnormalities<br>• Laryngomalacia, hypotonia<br>• GERD<br>• Pulmonary HTN, cor pulmonale<br>• Systemic HTN |
| Night-time<br>• Snoring (most common) | |

- Gasping or noisy breathing
- Restless sleep
- Paradoxical breathing
- Witnessed apnea
- Retractions and neck hyperextension
- Nocturnal sweating
- Enuresis
- Parasomnia (walking, talking, night terrors)

## Treatment

First-line treatment is tonsillectomy +/– adenoidectomy with an efficacy up to 80%. However, obesity significantly reduces the success of tonsillectomy for treatment of OSA. Risks of tonsillectomy include:

- Pain
- Dehydration
- Upper airway obstruction
- Postoperative respiratory complications—increased risk in:
  - Age <3 years
  - Severe OSA
  - Obesity
  - Cardiovascular comorbidities associated with OSA
  - Failure to thrive
  - Craniofacial abnormalities
  - Neuromuscular disorder
  - Current URI
- Postoperative hemorrhage
- Velopharyngeal incompetence
- Nasopharyngeal stenosis
- Death

Second-line treatment for OSA in the pediatric population is continuous positive airway pressure (CPAP), that is, home nasal CPAP. Additionally, weight loss is also recommended in obese children with OSA.

## Perioperative Concerns for Obese Children With and

## Without OSA

The pediatric anesthesiologist is now facing unique challenges when providing perioperative care for overweight and obese children and adolescents. The prevalence of obese children ages 6 to 19 is now estimated at 16% and these children are presenting for surgical procedures (i.e., adenotonsillectomy and bariatric weight loss procedures). Physiologic changes and comorbidities related to obesity that must be considered perioperatively are outlined below.

## Cardiovascular

- Systemic hypertension
- Sympathetic nervous system hyperactivity
- Increased cardiac output
- Increased blood volume
- Increased oxygen consumption and carbon dioxide production
- Obesity cardiomyopathy
- Pulmonary hypertension in OSA secondary to chronic hypoxemia, hypercarbia and acidosis leading to vasoconstriction of pulmonary arteries that may progress to cor pulmonale

## Respiratory

- Reduced chest wall compliance
- Pulmonary function tests (PFTs) consistent with restrictive pattern of disease
  - Decreased functional residual capacity
  - Decreased expiratory reserve volume
  - Decreased vital capacity
  - Decreased inspiratory capacity
- Increased incidence of obstructive lung diseases such as asthma
- OSA: chronic hypoxemia +/– hypercarbia
- Increased atelectasis than normal weight patients and consequential air trapping with pulmonary shunting

## Endocrine

- Type 2 diabetes mellitus
- Insulin resistance
- Metabolic syndrome

Anesthetic management of overweight and obese children can be further broken into pre-, intra-, and postoperative concerns.

## Preoperative Considerations

- Preoperative Assessment
  - OSA screen: presence of snoring, failure to thrive, developmental delay, nasal anatomy, abnormal facies (elongated, mandibular size, intermaxillary distance), tonsillar size, tongue volume, body habitus
  - Mallampati score
- Consider preoperative CPAP for patients with severe OSA
- Premedication:
  - Unreliability of intramuscular injection
  - Possible respiratory depression from sedation

## Intraoperative Considerations

- Patient Monitoring:
  - Electrocardiogram impedance secondary to excessive adipose tissue
  - Unreliable pulse oximetry secondary to excessive soft tissue
  - Difficulty sizing noninvasive blood pressure cuffs to obtain accurate readings
  - Possible inaccurate end tidal $CO_2$ monitoring secondary to decreased FRC, V/Q mismatch and dead space to tidal volume changes
  - Neuromuscular blockade monitoring may be unreliable secondary to increased soft tissue
- Patient positioning
  - Nerve injury
  - Cardiopulmonary changes—supine positioning leads to vascular redistribution (increasing venous return, pulmonary blood flow, cardiac output, arterial blood pressure) and also creates ventilation difficulties secondary to decreased diaphragmatic excursion
- Induction
  - Mask induction with volatile anesthetic may place child with OSA at risk for airway obstruction secondary to muscle relaxation and airway collapse
  - Oral airway may be helpful for relieving airway obstruction
  - IV induction with rapid-acting agent may aid in airway instrumentation of patient with OSA
- Emergence
  - Adequate strength and consciousness should be achieved prior to tracheal extubation
  - Consider nasal airway in patient with severe OSA as these patients are at risk for postoperative OSA

## Postoperative Concerns

- Patient positioning
  - slightly head up (30 to 45 degrees) to improve ventilation
  - prone or lateral positioning in patient with persistent obstruction
  - CPAP or BiPAP may be required for patients with persistent OSA
- Reduce postoperative nausea and vomiting
  - Steroids have been shown to reduce pain and vomiting in patients undergoing adenotonsillectomy
  - Antiserotonergics
- Pain management
  - Children with OSA are more sensitive to respiratory depressant effect of opioids given chronic hypoxemia
  - Regional anesthesia when possible
  - Nonopioid analgesics such as nonsteroidal anti-inflammatories or acetaminophen
- Respiratory complications
  - OSA increases risk of postoperative respiratory complication such as oxygenation desaturation, changes on chest radiograph, increased work of breathing, laryngospasm, apnea, pulmonary edema
- Patient discharge
  - Severe OSA may require overnight monitoring, especially if opioids required for pain management

## TAKE HOME POINTS

- Child and adolescent obesity is a growing concern that affects perioperative management of the patient.
- Obesity leads to comorbidities in nearly all organ systems which necessitates a thorough preoperative assessment by the anesthesiologist.
- In order for anesthesiologists to safely care for these children, the direct and indirect consequences of obesity on the child must be understood and considered carefully when formulating an anesthetic plan.

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# Neuromuscular Disease in Kids Can Be Very Challenging Because You Don't Always Have a Definitive Diagnosis—Here's How to Approach the Clinical Situations

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Anesthetic management in children with neuromuscular disease can be challenging, as many of these patients lack a definitive diagnosis when presenting for procedures such as muscle biopsy. Anesthetic considerations in the hypotonic child with possible neuromuscular disease include:

- Respiratory insufficiency due to muscle fatigue and weak cough
- Increased incidence of cardiomyopathy, conduction abnormalities, and arrhythmias
- Potential for difficult airway, from hypertrophied tongue or contractures
- Dysphagia and acid reflux, with increased risk of pulmonary aspiration
- CNS involvement, which can manifest as psychomotor retardation or refractory epilepsy
- Increased risk of rhabdomyolysis and possibly malignant hyperthermia (MH)

Neuromuscular diseases can be broadly categorized in the following groups: Muscular dystrophy, myotonic dystrophy, congenital myopathies, mitochondrial disease, and MH. We will briefly describe each muscle disorder, focusing on the anesthetic implications and perioperative management of each.

## Muscular Dystrophies

**Duchenne muscular dystrophy (DMD)** is the most common childhood dystrophy with an incidence of 1:3,500 live male births. It is a progressive X-linked, recessive disease. Those affected have very abnormal or absent dystrophin, a protein which stabilizes and links myofibrils and cytoskeleton in all muscle types. This leads to muscle fiber necrosis and degeneration/regeneration. Creatine kinase (CK) levels are elevated from birth and can be as high as 50 to 300 times normal values. Patients typically present with proximal muscle weakness, waddling gait, calf pseudohypertrophy, and are usually

wheelchair bound by 5 years or 6 years old. Progressive paraspinal and respiratory muscle weakness leads to kyphoscoliosis and decreased vital capacity with recurrent respiratory infections. Degenerative muscle fibers in cardiac muscle may result in cardiomyopathy, conduction abnormalities, and arrhythmias.

Perioperative management begins with a detailed family history, as up to 90% of patients with DMD will have a positive family history. ECG may show resting tachycardia (often the first symptom of cardiac dysfunction), evidence of RV strain, inverted T waves, tall R waves, and deep Q waves. Systolic dysfunction and dilated cardiomyopathy may be present on echocardiography. A vital capacity of less than 30% predicted is associated with increased risk of pulmonary complications.

**Succinylcholine is absolutely contraindicated in the Duchenne muscular dystrophy patient population**, as it can lead to rhabdomyolysis and hyperkalemic arrest. Volatile agents are controversial in this group, as there have been reports of rhabdomyolysis and perioperative cardiac arrest with their use. This phenomenon is also known as anesthetic-induced rhabdomyolysis (AIR), which is a distinct entity often confused with MH. It is caused by instability of the sarcolemma, which leads to potassium and CK leak from the sarcolemma. Upregulation of the acetylcholine receptors secondary to muscle regeneration may also play a role. Children under the age of 8 years are at increased risk because there is still some muscle generation. Many providers choose a nontriggering anesthetic to potentially avoid this life-threatening complication. Volatile agents may also cause profound myocardial depression in DMD patients, as they are prone to cardiac complications and cardiomyopathy, which may be undiagnosed at the time of the anesthetic.

Other factors that must be considered include possibility of difficult laryngoscopy due to glossal hypertrophy and limited neck mobility. Contractures may make IV access challenging. These patients also have increased sensitivity to neuromuscular blocking drugs (NMBDs), leading to prolonged recovery. Regardless of the type of procedure, all of these patients warrant close cardiopulmonary monitoring postoperatively as well as serial CK monitoring, as rising values from baseline could be a sign of AIR.

**Becker's muscular dystrophy (BMD**) is the second most common form of muscular dystrophy, with an incidence of approximately 1:30,000 live male births. The dystrophin protein is abnormal, but still partially functional, which yields milder symptoms with a slower onset than DMD. Symptoms typically appear around age 11, and include delayed motor milestones, difficulty getting up, and toe-walking. CK levels are elevated to about 50 to 100 times normal, less than in DMD. There is an increased incidence of arrhythmia; in addition, dilated cardiomyopathy and severe cardiac dysfunction may be present on echocardiography. Anesthetic management is similar to patients with DMD (see above).

## Myotonic Dystrophy

**Myotonic dystrophy or Steinert disease** is a systemic autosomal dominant disease caused by a mutation on chromosome 19 that leads to persistent muscle contraction following stimulation. Symptoms present in early adulthood and include cardiac, respiratory, neurologic, and gastrointestinal dysfunction. Up to 50% to 90% of patients may have conduction deficits on ECG. Cardiomyopathy with interstitial fibrosis and possible mitral valve prolapse may be present on echocardiography. These patients have significant bulbar, intercostal, and diaphragm weakness, which can lead to dysphagia with recurrent aspiration pneumonia, poor nutrition, weak cough, and alveolar hypoventilation. Seizures, cataracts, and retinal detachment are also common. Like patients with muscular dystrophy, CK can be elevated, but levels do not correlate with disease severity.

Perioperative management begins with a thorough history, focusing on developmental delays, hospitalizations, respiratory infections, and any signs of cardiac dysfunction. Myotonic dystrophy patients are exquisitely sensitive to the respiratory depressant effects of sedative premedication. If sedation is needed, it is important to provide supplemental oxygen and have appropriate monitors and airway equipment readily available. A multimodal analgesic approach with NSAIDs, acetaminophen, and regional anesthesia should be used when possible to minimize opioid use. Due to weak pharyngeal muscles, dysphagia, and delayed gastric emptying, RSI is recommended to prevent aspiration; however, succinylcholine should not be used as these patients are at increased risk for rhabdomyolysis and hyperkalemic cardiac arrest. TMJ contractures may make laryngoscopy difficult; in addition, TMJ dislocation with laryngoscopy has also been reported. These patients can have an exaggerated response to NMBDs, which should be avoided if possible. If more relaxation is needed, options include deepening anesthetic or injecting local anesthetic into the skeletal muscle. Of note, NMBDs do not prevent or reverse myotonic contraction. Phenytoin, steroids, and volatile anesthetics can attenuate contractions. Depolarizing muscle relaxants, cholinesterase inhibitors, potassium, hypothermia, shivering, and mechanical/electrical stimulation can exacerbate myotonia; therefore, it is important to avoid IV fluids containing potassium, maintain normothermia, and provide adequate analgesia.

The myotonic dystrophy patient population is not more susceptible to MH than the general population; some argue that a nontriggering anesthetic be used, but others have successfully administered a volatile anesthetic without complications. Regardless of the technique used, careful monitoring throughout the perioperative period is critical. If the patient has significant conduction abnormalities, defibrillator pads should be placed intraoperatively as these patients are at high risk for malignant arrhythmias and sudden cardiac death. **In 1997, Matheiu et al. performed a retrospective analysis of over**

**200 myotonic dystrophy patients receiving general anesthesia and found that respiratory complications were most common. Furthermore, there is an increased risk of delayed apnea up to 24 hours postoperatively.** Even patients with very mild disease can manifest severe complications.

## Congenital Myopathies

**Congenital myopathies** are a group of nonprogressive muscle disorders that present with hypotonia and small muscle mass. Unlike the muscular dystrophies, there is no muscle necrosis or degeneration. Clinical symptoms include weakness and delayed motor milestones. Serum CK is normal or slightly elevated. Classification depends on histologic analysis of muscle tissue from biopsy, symptoms, and MRI. The best-known congenital myopathy is central core disease (CCD). Patients with CCD present with hypotonia at birth, proximal muscle weakness, and fatigue associated with feeding. The symptoms are rarely progressive. **CCD is a recessive trait, genetically linked to a defect in the chromosome 19 ryanodine receptor (RYR1), putting these patients at greatly increased risk for MH (see below). If CCD is suspected, a nontriggering anesthetic must be administered.**

## Mitochondrial Disease

**Mitochondrial diseases** are the most common cause of muscle weakness in children, with an incidence of 1:4,000. Mitochondria are responsible for aerobic respiration and energy generation via oxidative phosphorylation. ATP is generated by products of the Krebs cycle interacting with the electron chain transport chain on the inner mitochondrial membrane. In mitochondrial diseases, the electron transport chain is impaired, resulting in decreased ATP production. This decreased energy production results in increased free radical production and acidosis, which cause oxidative damage to the mitochondrial proteins, lipids, and DNA. This damage is most pronounced in tissues with high metabolic demand, such as the heart, brain, and muscles. Some common mitochondrial disease are listed in Table 193.1.

**Table 193.1 ■ Common Mitochondrial Diseases**

| | Symptoms |
|---|---|
| MELAS | Mitochondrial encephalopathy, lactatic acidosis, and stroke |
| MERRF | Myoclonic epilepsy with ragged red fibers |

| | |
|---|---|
| Acid maltase deficiency | Severe respiratory issues<br>Recurrent aspiration pneumonia<br>Pulmonary arterial hypertension |
| Kearns–Sayre syndrome | Deletions in mitochondrial DNA |
| Lipid storage deficiency | Hypoglycemia<br>Acidosis<br>General muscle weakness<br>Rhabdomyolysis<br>Progressive cardiac dysfunction |

Generalized symptoms include hypotonia, small stature, developmental delay, episodes of hypoglycemia, and poor feeding.

Perioperative management of these patients is challenging. Patients have an exaggerated response to prolonged fasting, which can result in hypoglycemia, dehydration and metabolic acidosis. IV fluids with dextrose and electrolytes should be continued in the perioperative period, but avoid fluids with lactate, as this can worsen acidosis. Frequent glucose checks are important to prevent hypoglycemia. In addition, stress, hypothermia, and pain can exacerbate metabolic disturbances and acidosis. Maintaining normothermia and providing adequate analgesia are important to prevent shivering and writhing.

Mitochondrial disease patients have increased sensitivity to sedatives, barbiturates, and propofol and have variable sensitivity to neuromuscular blockade. There are data suggesting that propofol infusion syndrome (PRIS) can occur in these patients because it contains long-chain fatty acids, which impairs mitochondrial respiratory chain function. Although PRIS usually occurs after 48 hours of propofol infusion at doses greater than 5 mg/kg/hr, it may occur at lower doses in those with mitochondrial disease. Symptoms of PRIS include rhabdomyolysis, cardiac dysfunction, severe metabolic acidosis, and renal failure. Succinylcholine should be avoided if possible, as there have been cases of MH in mitochondrial disease patients exposed to it. Furthermore, local anesthetics have been shown in animal studies to decrease respiratory chain activity and should be used cautiously in this patient population.

## Malignant Hyperthermia

**Malignant hyperthermia (MH)** is one of the most widely feared complications of anesthesia. Positive family history is the main way to identify at-risk patients. Other diseases associated with high risk of MH are central core disease (CCD), King–Denborough syndrome, and Evans myopathy. MH is autosomal dominant, with an

incidence of 1:15,000 in children to 1:50,000 adults. The underlying pathophysiology involves mutations in the ryanodine receptor (RYR1), which regulates the release of calcium from the sarcoplasmic reticulum (SR). When exposed to triggering agents, exaggerated calcium release from the SR leads to sustained muscle contraction and a hypermetabolic state. Triggers include succinylcholine and all volatile anesthetics. Symptoms include tachycardia, hypercarbia despite unchanged minute ventilation, muscle rigidity, rhabdomyolysis, hyperkalemia, and acidosis. Hyperthermia is a late sign; if left untreated, cardiac arrest and death occur in up to 60% of patients.

Perioperative management involves avoiding triggers in susceptible patients. This includes changing the $CO_2$ absorbent and flushing the anesthesia machine with high-flow oxygen for 10 minutes to eliminate trace volatile agents. If MH is suspected, early administration of dantrolene 2.5 mg/kg IV can drastically reduce mortality. In patients with strong family history, muscle biopsy with in vitro caffeine-halothane contracture test is recommended. It is 97% to 99% sensitive and 80% to 90% specific.

## TAKE HOME POINTS

- Despite the increasing breadth of knowledge regarding neuromuscular diseases, it is still challenging to care for an infant or child who presents with hypotonia, but no known diagnosis. In this situation, a nontriggering anesthetic is the most reasonable choice.
- If the diagnosis is known, there is a general consensus to use a TIVA for those with muscular dystrophy and a volatile agent for those with mitochondrial disease. In 2007, Flick et al. reviewed nearly 300 patients undergoing muscle biopsy for suspected neuromuscular disease. They all received volatile agents with or without succinylcholine and no child was noted to have rhabdomyolysis or MH. From this, they estimated the risk of developing MH or rhabdomyolysis after administration of volatile anesthetic in the setting of neuromuscular disease to be less than or equal to 1.09%, compared to a presumable risk of near zero in patients without suspected neuromuscular disease.
- **Be vigilant for signs of rhabdomyolysis and MH**; if MH is suspected, discontinuing all triggering agents, hyperventilation with 100% oxygen, and prompt administration of IV dantrolene may be life-saving. If hyperkalemia is suspected, follow the AHA guidelines for treatment: 0.5 mL/kg of 10% calcium gluconate or calcium chloride, 0.5 g/kg of dextrose with 0.05 units/kg of insulin, and consider sodium bicarbonate and a β2-agonist, such as albuterol.
- **The importance of careful preoperative evaluation of these patients cannot be overemphasized.** Thorough discussion regarding family history, previous anesthetic exposure, and previous history of anesthetic complications in family members is

imperative. Further investigation is still needed to determine the safest anesthetic possible for this heterogeneous patient population.

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# Pediatric Patients With Epilepsy: Considerations for Patients on a Ketogenic Diet and for Cortical Mapping

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Epilepsy is a disorder where unprovoked, recurrent seizures are caused by abnormal electrical discharges within the brain. Children are particularly susceptible to seizures and most epilepsy begins in childhood. These patients are often complex needing special attention regarding their intraoperative management. This chapter discusses special, but not uncommon scenarios:

) The perioperative management for patients on a ketogenic diet.
) The management of the patient for epilepsy surgery with intraoperative mapping.

## Ketogenic Diet

Most seizures can be controlled by a single antiepileptic medication, but sometimes seizures develop which are resistant to these medications or the side effects of the medications become intolerable. The ketogenic diet has been widely used to treat children with drug-resistant epilepsy since the 1920s. It is a high fat, low carbohydrate, with adequate protein diet. While the exact mechanism of action is still unclear, it is hypothesized that the high fat and restricted carbohydrate content of the diet mimics what the body does under periods of starvation where ketone bodies become the main source of fuel for the brain's energy demand. Somehow this metabolic transition is associated with improved seizure control. The ketogenic diet is based on a ratio of fat:carbohydrate and protein of 3:1 or 4:1. Medium chain triglycerides (MCT) is a modification to the classic ketogenic diet. MCT yield more ketones than long chain triglycerides do, and they are absorbed more efficiently and the diet is more palatable; therefore, it has been gained in popularity in recent years. If the seizures are successfully controlled or decreased in frequency then the diet is usually continued for about 2 to 3 years.

Complications of the diet include the potential for hypoglycemia, ketosis with

associated lethargy, nausea, vomiting, and even coma. It is possible to have platelet dysfunction while on the diet as well as cardiac complications such as prolonged QTc and possible cardiomyopathy.

Intraoperative management of patients on a ketogenic diet has to be thoughtful. Some centers seem to taper or discontinue the ketogenic diet before surgery, whereas others continue the diet. But if a patient with refractory epilepsy has responded well to a ketogenic diet, it seems most of the time advantageous to keep the patient in the ketogenic state throughout the procedure. A consultation with the patient's dietitian and/or pediatric neurologist can be helpful to develop a practical plan. If one wants to keep the patient in a ketogenic state, it is advised to try not to administer glucose or dextrose containing medications or medication which could potentially increase the glucose level.

**With this goal, the anesthesiologist must remember that many oral medications contain significant amounts of carbohydrate. In the perioperative environment, acetaminophen syrup and oral midazolam come to mind especially.** Other intravenous drugs, such as premixed dopamine, often contain dextrose 5% and should be avoided if possible, since dopamine, like many other medications, is also available in a solution without dextrose 5%. Red blood cells also contain dextrose and will interfere with the ketogenic state of the patient, though this does not preclude transfusion. Another drug which is relatively contraindicated is dexamethasone, since it increases the blood glucose level after administration. Since the primary energy source in the ketogenic diet —the ketone bodies—are only formed in the liver, it can be argued that an anesthetic that does not interfere with the liver function is preferred. Long-duration propofol infusions with the risk of causing metabolic acidosis as a result of the propofol infusion syndrome might therefore not be ideal for this patient group. We recommend reviewing the planned anesthetic drugs with the pharmacist to minimize the risk of disrupting the ketogenic status. For long surgeries, one should monitor the blood glucose level to maintain low to normoglycemia. Serum pH and bicarbonate levels are also useful to monitor for acidosis. Lactated Ringer's or normal saline solutions have both been used without problems.

## Cortical Stimulation Mapping

Cortical stimulation mapping (CSM) is routinely used for patients with epilepsy in order to pinpoint the seizure focus. It is usually considered when a patient with epilepsy has failed antiepileptic drug therapy and it is likely that surgery will benefit the patient. In older, more cooperative adolescents and adults, it may be possible to accomplish cortical mapping while the neurosurgeon performs an "awake" craniotomy, whereby the patient is sedated with intravenous anesthetics and analgesics such as propofol,

remifentanil, or dexmedetomidine during the infiltration of local anesthetic to the scalp and skull resection by the surgeon. This can be the most stimulating part, so it is important to achieve adequate analgesia and sedation but still be able to maintain the patient spontaneously ventilating as they will need to awaken to assist the surgeon in determining whether the seizure focus is near a cortical area that controls vital functions such as speech, motion, and sensation.

Once the targeted area has been identified and resected, the patient is then sedated again for the craniotomy closure. It is important to remember that these are patients with epilepsy and are at risk of having a seizure during the procedure. Be prepared by having propofol or midazolam readily available to bolus if needed to treat a seizure. It is also imperative to maintain adequate access to the patient's airway under the surgical drapes should the airway need to be secured emergently. Having an appropriate size LMA readily available is a must.

Children usually less than 10 years of age, or with developmental delays or learning disabilities are not the best candidates for this "awake" approach and usually require general anesthesia throughout the procedure. In these situations, cortical mapping is accomplished with electroencephalogram (EEG) monitoring, somatosensory evoked potentials (SSEP), and motor stimulation. Utilizing an anesthetic technique such as total intravenous anesthesia (TIVA) or 0.5 minimum alveolar concentration (MAC) of inhalation anesthetic combined with an intravenous infusion of narcotic or propofol will provide good conditions for obtaining adequate neuromonitoring signals and help maintain the integrity of the EEG. Another option is to use dexmedetomidine with propofol and opioid. Dexmedetomidine seems to stabilize the neuromonitoring signals quite nicely. It is even feasible to pause the propofol infusion for the 20 minutes where the grid has been placed while running high-dose dexmedetomidine (1 to 2 μg/kg/hr) and high doses of opioid infusion with excellent EEG signals. A bispectral index (BIS) monitor is added if appropriate to monitor changes in anesthesia levels accordingly. Remember that if motor testing is to be performed during the procedure, avoid administering muscle relaxants.

In situations where the seizures are generalized it is challenging to identify the focus. Evaluation with intracranial EEG monitoring otherwise known as "grids and strips" may be accomplished by direct electrocorticography. Here, the electrode leads are placed directly on the patient's cortex following a craniotomy after general anesthesia. Over the next few days, the patient is closely monitored to see if one or more seizure foci can be identified. It is important to remember that air can persist within the skull after a craniotomy so when the patient is taken back to the operating room (OR) for resection of the identified foci or to remove the electrodes, it is imperative to avoid nitrous oxide as this could create a tension pneumocephalus.

## TAKE HOME POINTS

- Patients on ketogenic diet need extra time for the perioperative evaluation. Consider contacting your pharmacy and the patient's dietitian or pediatric neurologist to develop a plan.
- Some perioperative drugs interfere with the ketogenic diet and are relatively contraindicated. This includes oral midazolam and acetaminophen; dexamethasone; other dextrose containing drugs such as dopamine, epinephrine, and red blood cells; and propofol.
- Blood glucose levels and serum pH or bicarbonate should be monitored, especially in longer procedures.
- CSM can be done "awake" in the older adolescent who does not have cognitive deficits. "Awake" means spontaneously breathing and able to respond to the surgeon's queries, it does not mean "no anesthesia." Propofol, remifentanil, and lidocaine are still appropriate and even required for opening the scalp and cranium and then again for craniotomy closure.
- Remember always that these are seizure patients and they can have a seizure at any time. Be ready with midazolam or propofol to bolus if a seizure occurs.
- It is imperative to retain access to the patient's airway, even while under the drapes. The appropriate size LMA, readily at hand, is a must.
- Younger children (less than 10 years of age) and any child with a cognitive delay or deficit should have a general anesthetic. A variety of general anesthetic techniques are available. Dexmedetomidine-based anesthetics work well in this situation.
- If your patient is coming back to the OR to have cortical electrodes removed, it is imperative that you avoid using nitrous oxide to minimize the risk of tension pneumocephalus.

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# Neonates Deserve Perioperative Analgesia, Too

Raquel G. Hernandez, DO and Angela Kendrick, MD (Retired)

Pediatric pain management may be as "simple" as providing a single-shot caudal with local anesthetic for postoperative pain relief or as "complex" as providing consultative and management services for children with sickle cell disease, cancer pain, or complex regional pain syndromes. With a greater understanding of neonatal physiology and pharmacology, we know that neuroendocrine responses to stress, increased tissue catabolism, and postoperative pulmonary functions can be favorably modified by providing adequate postoperative analgesia.

This chapter is intended to provide you with some strategies for evaluating pediatric pain, to remind you of important pharmacokinetic and anatomic differences between infants and children on the one hand, and adults on the other, and to provide you with some tips on avoiding common mishaps associated with the treatment of acute pain in children.

## Evaluation of Pain

You must choose the appropriate pain scale and implement objective observation in the preverbal child. Pain scales are the tools you use to document the presence and severity of pain and the effectiveness of your treatment. Objective rating systems rely on physical signs of increased sympathetic activity in conjunction with behavioral assessments.

There are a number of behavior-based pain scales. The Children's Hospital of Eastern Ontario Pain Scale (CHEOPS) (Table 195.1) was developed by McGrath et al. to assess pain in the postanesthesia care unit (PACU). Six categories of behavior (crying, facial expression, verbal expression, movement of torso, touching of wound, and movement of legs) are observed and scored, and an appropriate number is charted to indicate the presence or intensity of a response. A score greater than 4 indicates pain and should be treated appropriately. If the expected response to an adequate dose of analgesic is not observed, an attempt should be made to comfort the child with

behavioral interventions. If this is not successful, then additional analgesia should be considered.

**Table 195.1 ■ Children's Hospital Eastern Ontario Pain Scale (CHEOPS). Recommended for Children of 1 to 7 Years of Age; a Score Greater Than 4 Indicates Pain.**

| Item | Behavioral | Points | Definition | Score |
|---|---|---|---|---|
| **Crying** | No crying | 1 | Child is not crying. | |
| | Moaning | 2 | Child is moaning or quietly vocalizing; silent cry. | |
| | Crying | 2 | Child is crying, but the cry is gentle or whimpering. | |
| | Scream | 3 | Child is in a full-lunged cry; sobbing; may be scored with complaint or without complaint. | |
| **Facial** | Composed | 1 | Neutral facial expression. | |
| | Grimace | 2 | Score only if definite negative facial expression. | |
| | Smiling | 0 | Score only if definite positive facial expression. | |
| **Verbal** | None | 1 | Child not talking. | |
| | Other complaints | 1 | Child complains, but not about pain, e.g., "I want to see mommy" or "I am thirsty." | |
| | Pain complaints | 2 | Child complains about pain. | |
| | Both complaints | 2 | Child complains about pain and about other things, e.g., "It hurts; I want my mommy." | |
| | Positive | 0 | Child makes any positive statement or talks about others things without complaint. | |

| | | | |
|---|---|---|---|
| **Torso** | Neutral | 1 | Body (not limbs) is at rest; torso is inactive. |
| | Shifting | 2 | Body is in motion in a shifting or serpentine fashion. |
| | Tense | 2 | Body is arched or rigid. |
| | Shivering | 2 | Body is shuddering or shaking involuntarily. |
| | Upright | 2 | Child is in a vertical or upright position. |
| | Restrained | 2 | Body is restrained. |
| **Touch** | Not touching | 1 | Child is not touching or grabbing at wound. |
| | Reach | 2 | Child is reaching for but not touching wound. |
| | Touch | 2 | Child is gently touching wound or wound area. |
| | Grab | 2 | Child is grabbing vigorously at wound. |
| | Restrained | 2 | Child's arms are restrained. |
| **Legs** | Neutral | 1 | Legs may be in any position but are relaxed; includes gentle swimming or serpentine-like movements. |
| | Squirming or kicking | 2 | Definitive uneasy or restless movements in the legs or striking out with foot or feet (or both). |
| | Drawn up or tensed | 2 | Legs tensed or pulled up tightly to body and kept there. |
| | Standing | 2 | Standing, crouching, or kneeling. |
| | Restrained | 2 | Child's legs are being held down. |

From McGrath PJ, Johnson G, et al., with permission from The Medical Algorithms Company Ltd. available at www.MedicalAlgorithms.com.

The Face, Legs, Activity, Cry, and Consolability (FLACC) scale (Table 195.2) is simpler than CHEOPS and is popular for the assessment of both infants and older, nonverbal patients. Parents or chronic caregivers of children with cognitive impairment have been shown to be sensitive to their child's method of expressing pain. This input

can be invaluable for interpreting the developmentally disabled child's responses.

**Table 195.2 ■ Face, Legs, Activity, Cry, and Consolability (FLACC) Behavioral Pain Assessment Tool**

| Category | Description | Score |
|---|---|---|
| Face | 0 = No particular expression or smile | 0 |
| | 1 = Occasional grimace/frown, withdrawn or disinterested | 1 |
| | 2 = Frequent/constant quivering chin, clenched jaw | 2 |
| Legs | 0 = Normal position or relaxed | 0 |
| | 1 = Uneasy, restless, tense | 1 |
| | 2 = Kicking or legs drawn up | 2 |
| Activity | 0 = Lying quietly, normal position, moves easily | 0 |
| | 1 = Squirming, shifting back and forth, tense | 1 |
| | 2 = Arched, rigid, or jerking | 2 |
| Cry | 0 = No cry | 0 |
| | 1 = Moans or whimpers, occasional complaint | 1 |
| | 2 = Crying steadily, screams or sobs, frequent complaints | 2 |
| Consolability | 0 = Content and relaxed | 0 |
| | 1 = Reassured by occasional touching, hugging or being talked to, distractible | 1 |
| | 2 = Difficult to console or comfort | 2 |



The Neonatal Infant Pain Scale (NIPS) is another pain scale developed by McGrath et al. that can be used for term and preterm infants alike (see Table 195.3). It was adapted from the CHEOPS scale and focuses more on behavioral components that are indicative of infant pain or distress. The six indicators are: facial expression, cry, breathing pattern, arms, legs, and state of arousal. Total pain score range is from 0 to 7.

A score of >4 should prompt nonpharmacologic interventions (repositioning, changing diaper, feeding) along with a pharmacologic intervention and reassessment within the next 30 minutes. Keep in mind that a drug-exposed infant could score high due to withdrawal symptoms and critically ill patients may score low because they are too ill to mount a behavioral response to pain/agitation. DO NOT assign a NIPS score to paralyzed/deeply sedated infants. Assess adequacy of analgesia in these patients with another scale and by using vital signs.

**Table 195.3 ■ Neonatal Infant Pain Scale (NIPS)**

| NPS | 0 point | 1 point | 2 points |
|---|---|---|---|
| Facial expression | Relaxed | Contracted | — |
| Cry | Absent | Mumbling | Vigorous |
| Breathing | Relaxed | Different than basal | — |
| Arms | Relaxed | Flexed/stretched | — |
| Legs | Relaxed | Flexed/stretched | — |
| Alertness | Sleeping/calm | Uncomfortable | — |

NIPS chart created by McGrath, et al., and available at https://www.medicalalgorithms.com/neonatal-pain-scale, with permission.

Observing physiologic parameters (heart rate, respirations, blood pressure, body temperature) is standard practice in evaluating a patient's overall condition. Physiologic variables are also incorporated into pain assessment, with rapid shallow breathing, elevated heart rate, and increased blood pressure possibly indicating the presence of pain.

Other methods of pain assessment, such as verbal self-report, use of numeric scales, and use of the faces scale, are appropriate for use in older children but have their disadvantages. For example, the child may want to avoid a potential painful encounter (fear of needles), so the child denies any pain. A child may fail to understand ordinal numbers and pick a higher "better" number, or the child may pick the smiley face on the faces scale because it is the face he or she likes the best.

## Know Your High-Risk Populations

Infants younger than 3 months of age, infants born prematurely that are less than 60 weeks postmenstrual age (formerly called postconceptual age), and any child with a

history of apnea or airway compromise, cardiac compromise, anemia (Hct <30%), or neuromuscular disease are at risk for cardiorespiratory complications following opioid or sedative administration. You need to carefully titrate your dose and monitor these children after administration of opioids or sedatives. **To keep things simple, it is recommended to admit and monitor all former preterm infants of less than 60 weeks postconceptual age overnight after surgery.**

**Premature Infants and Neonates Require Special Consideration.** We now know that the preterm infant has the neurophysiologic pathways to experience pain and the inhibitory pathways for modulating the pain response are less developed. Inadequate relief of pain in the neonatal intensive care unit may lead to an accelerated catabolic response, with increased secretion of stress hormones and altered sleep–wake cycles. Inadequate pain relief in the very young may lead to a long-term altered response (increased sensitivity) to pain.

**Drug Metabolism in the Neonate.** Newborns have lower levels of plasma proteins, including albumin and alpha-(1)-acid glycoprotein, than do adults. When protein-bound drugs are administered, newborns have a higher free fraction of drug, which is the pharmacologically active form, than do adults.

Infants may have physiologic processes that impair renal or portal blood flow (necrotizing enterocolitis, abdominal compartment syndrome, reduced systemic cardiac output), so metabolism and elimination of drugs may become unpredictable.

**Newborns are slow metabolizers due to liver immaturity**. This ability rapidly increases during the first 3 months of life. Hepatic metabolism occurs in two phases:

a) Phase 1 (oxidation, hydroxylation, and hydrolysis or reduction) involves the cytochrome P450 enzyme system.
b) Phase II enzymes conjugate the metabolites of the phase 1 reactions. Phase II conjugation with glucuronyl transferases may be also be impaired in the newborn.

Since the kidney clears both parent drug and metabolites produced by the liver, renal failure causes accumulation and potential toxicity.

## Planning Postoperative Analgesia

An analgesic plan should be established before induction of anesthesia because of the need to obtain consent for certain procedures if indicated (i.e., caudal or peripheral nerve block). Consulting with the surgeon will often provide information about the scope of the surgery and expectant postoperative care requirements. It is easier to maintain adequate analgesia in a patient who emerges and awakens from anesthesia comfortably than to try and achieve analgesia in a patient who is experiencing severe

pain.

## Drug Therapy for Acute Pain

**Opioid Infusions in the Neonate.** Pain from a variety of causes can be managed via a continuous IV infusion with bolus supplementation. The two opioids most frequently used in the neonate are morphine and fentanyl. **Neonates who are not intubated need particularly careful monitoring**. Common pitfalls of intermittent injections with opioids of short or moderate duration of actions include difficulty achieving a stable plasma level and the potential for periods of excessive sedation alternating with periods of inadequate analgesia.

a) Morphine does not require Phase I metabolism but undergoes Phase II glucuronidation, producing morphine 3 glucuronide (nonactive) and morphine 3,6 diglucuronide (active). **Morphine has a prolonged half-life in neonates** (6.8 hours and up to 10 hours in the preterm infant). The loading dose range for IV administration is 50 to 100 μg/kg. The amount of drug used in constant-infusion doses depends on the patient's rate of metabolism, degree of pain, and other individual characteristics.
b) Fentanyl is highly bound to alpha-(1)-acid glycoprotein. Its elimination half-life is prolonged in premature infants and newborns and is even more prolonged after a continuous infusion. The "context-sensitive half time" refers to the time for drug concentration at the sites of action to decrease by half. Newborns receiving fentanyl infusions for longer than 36 hours have a context sensitive half time of greater than 9 hours. Initial IV dosing for acute pain is 0.5 to 1 μg/kg. Continuous-infusion rates are highly variable and depend on the degree of pain, the duration of administration, and the development of tolerance (see below).
c) It is necessary to observe patients on continuous infusions closely because there is potential for drug accumulation followed by respiratory depression which could take several hours to occur as the dose administered per hour in the infusion is typically small and the rate of increase in blood will be slower than a bolus dose.

## Patient-Controlled Analgesia for Children

- Use of standard preprinted Patient-Controlled Analgesia (PCA) order sheets, with suggested dose ranges, monitoring standards, and discontinuation of other sedative medications, is important in the care of any infant or child receiving continuous opioid therapy. **The orders, the infusions, and their pumps must be reviewed on a daily**

**basis**.

- If true PCA is to be used (rather than a continuous nonadjustable infusion), the child must understand how to push the button. The lockouts must be preset so that only a safe hourly maximum dose is delivered. A modality based on "PCA by proxy," with the parents or nurse pressing the "pain button," is also used in a number of hospitals. **This form of "PCA" is very controversial.** Carefully select the patients for parent- or nurse-controlled analgesia, closely monitor the patients for side effects, and ensure adequate analgesia is being maintained. This technique is most often used in the setting of palliative care; however, if used for postoperative analgesia a different approach consisting of a longer lock-out period (15 minutes vs. 5 or 6 minutes) with a slightly greater dose can reduce the frequency of the nurse or parent having to push the button.
- Infants and children receiving continuous infusions of opioids develop tolerance and require increasing doses to maintain the same effect. Animal models show that young animals develop tolerance at a quicker rate than do adult animals. If continuous opioid infusion therapy has been used for longer than 5 to 7 days, abrupt discontinuation may result in withdrawal symptoms. The duration of drug exposure and the accumulated amount of drug administered are factors to consider when planning your weaning protocol. Weaning protocols usually reduce opioids by 10% to 20% per day, with careful observation for tachycardia, diarrhea, irritability, or other signs of opioid withdrawal. Long-acting opioids, such as methadone and the alpha agonist clonidine, are sometimes useful to assist with the weaning process.

**Adjuncts Other than Opioids.** Multimodal therapy is important in treating postoperative pain. Acetaminophen (orally or rectally) given as a scheduled medication (not on an as-needed basis) has a significant opioid-sparing effect. Other nonsteroidal analgesics (ketorolac) should also be considered for use. Keep in mind that ketorolac can affect bleeding time and may be of limited use in procedures such as tonsillectomies. Impaired bone healing is also a concern with its use following complex spinal fusions. It is best to discuss with the patient's surgeon whether or not it is an acceptable analgesic to use for the patient and specific case. Ketamine (small dose, <0.5 mg/kg IV) has also been used in the PACU and in low-dose infusions postoperatively. It is a noncompetitive antagonist of the N-methyl-D-aspartate (NMDA) receptor and produces a synergistic effect to opioid analgesia.

## Regional Anesthesia for Postoperative Pain

In contrast to blocks for adults, the majority of blocks for children are placed after the induction of general anesthesia. Detecting an intravascular injection with a test dose of local anesthetic (5 μg/mL of epinephrine) is less reliable in the presence of inhalational anesthetics. You must watch carefully for an increase in heart rate, a decrease in heart

rate, or a change in T-wave morphology (peaked T waves). Remember that blood pressure may not increase with intravascular injection. Because the child is anesthetized, central nervous system symptoms may be masked and cardiovascular collapse may seem to occur without warning.

There are important anatomic differences to remember when placing caudal blocks or lumbar epidurals in pediatric patients. The subarachnoid space extends to S3–4 in the newborn before rising to the adult level of S1 at about the age of 1 year. This means the cerebrospinal fluid space is easy to enter when placing a caudal block in an infant. The neonatal spinal cord also extends to a lower lumbar level as low as L3 before receding to the adult level of L1.

Single shot caudal blocks are widely used to provide postoperative pain relief for operations done below the level of the patient's umbilicus. Intravascular injection, intrathecal injection, and intraosseous injection are all complications associated with this block. Careful advancement of the needle, with gentle aspiration after advancement, test dosing, continuous electrocardiogram monitoring, and incremental dosing will help you avoid catastrophic events.

As noted above, local anesthetic toxicity may develop acutely if the local anesthetic is inadvertently given intravenously or intraosseously. Toxicity may also be the result of accumulation of the local anesthetic with continuous, repeated, or inappropriately large dosing.

As with opioids, the pharmacokinetics of local anesthetic metabolism are different in infants. The amide anesthetics are metabolized through the immature cytochrome P450 system. Infants have a higher steady-state volume of distribution for local anesthetics than do adults, which leads to a prolonged half-life in infants. Local anesthetics are bound by alpha-(1)-acid glycoproteins; accordingly, a higher fraction of free drug exists in infants.

Infants younger than 4 months of age who receive continuous infusions of local anesthetics (e.g., caudal epidural infusions of bupivacaine) develop increasing plasma levels of bupivacaine. The toxic plasma level of bupivacaine is in the range of 4 μg/mL. The increasing plasma levels over time, as well as case reports of infants having toxic reactions (seizures, cardiac toxicity) while receiving higher dose infusions, have led to recommendations that infants younger than 4 months of age receive no more than 0.2 to 0.25 mg/kg/hr of bupivacaine. The duration of the infusion should be 48 hours or less. Older infants and children may receive bupivacaine infusions of 0.4 to 0.5 mg/kg/hr.

Ropivacaine has been studied in infants and similar pharmacokinetics apply. An initial epidural dose of 1 to 2 mg/kg, followed by an infusion of 0.2 mg/kg/hr for infants younger than 180 days of age and 0.4 mg/kg for infants older than 180 days of age, is considered safe.

Cardiac toxicity with bupivacaine can be very difficult to treat. Recent reports of adult cases and results from studies done in dogs have suggested that a 20% intralipid infusion may be the first-line therapy. The recommended dose for treatment of local anesthetic toxicity per the American Society of Regional Anesthesia and Pain Management (ASRA) is 1.5 mL/kg over 1 minute, and it may be repeated twice every 3 to 5 minutes, followed by an infusion at 0.25 mL/kg/min until the patient is hemodynamically stable.

## TAKE HOME POINTS

- Select an appropriate pain scale for evaluating the child's pain.
- Family or care giver feedback is necessary in evaluating the child who has cognitive impairment.
- Premature infants, infants younger than 3 months of age, and children with cardiopulmonary compromise, sleep apnea, or neuromuscular disease have a higher risk of adverse events from opioid administration.
- Withdrawal symptoms may occur if administration of opioids is abruptly discontinued after 5 to 7 days of continuous infusion.
- The potential for local-anesthetic toxicity with use of bupivacaine limits the infusion dose for infants to 0.2 to 0.25 mg/kg/hr.

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# Anesthetic Considerations in Patients With Fontan Physiology Who Present for Noncardiac Surgery

Kelly Ryan, MD and Angela Zimmerman, MD

## Introduction

The Fontan procedure is the third and final stage for children with congenital heart disease who are destined to have a single ventricle heart. It is a palliative procedure, but long-term outcomes for these patients have improved significantly due to better patient selection and management, and improved surgical techniques. In the current era, the Fontan operation is a total cavopulmonary circulation, consisting of placement of an extracardiac conduit between the inferior vena cava and the right pulmonary artery. The superior vena cava is already anastomosed to the right pulmonary artery from the Glenn operation (stage 2). With the Fontan, the right atrium is excluded from the systemic venous circuit.

## Physiology

An increasing number of Fontan patients have reached adolescence and adulthood; and are presenting for noncardiac interventions and surgeries. To best take care of these patients, one must understand the Fontan physiology. The idea behind a Fontan is that a right-sided pump is not needed to deliver venous blood return to the lungs. The primary force promoting pulmonary blood flow and hence cardiac output is the transpulmonary gradient—the difference between central venous pressure and systemic ventricular end-diastolic pressure. Oxygenated blood then drains into a common atrium and into the single ventricle that perfuses systemic circulation. How healthy the Fontan circulation is depends on systemic venous pressure and volume, pulmonary vascular anatomy and vascular resistance, underlying pulmonary disease, atrioventricular valve function, cardiac rhythm, and the function of the one and only systemic ventricle.

## Evaluation

As always, perioperative evaluation begins with a thorough history and physical examination. In addition to standard questions such as exercise capacity, the most recent catheterization or cardiac magnetic resonance imaging are extremely useful in evaluating cardiac anatomy, specifically transpulmonary gradient. Arterial oxygen saturation is typically between 90% and 95% in a nonfenestrated patient. A failing Fontan will have fatigue, decreased activity, weight gain or volume retention, palpitations, syncopal or presyncopal episodes, oxygen saturation below 90%, and dyspnea. Cardiomegaly or pleural effusions can be a sign of a failing Fontan**. Elective surgery should be delayed in a failing Fontan pending further evaluation.**

Similar to pediatric patients, IV fluids and medications must be deaired to avoid the risk of systemic air embolism given potential for right-to-left shunting. Premedication is recommended if a patient is anxious or in pain, as both pain and anxiety can cause the pulmonary vascular resistance (PVR) to increase; however, both should be titrated carefully to avoid hypoventilation and hypercarbia, which can also increase PVR. Also, patients with Fontan physiology have likely had a previous BT shunt. As such, upper-extremity blood pressure should be measured on the side opposite of the previous shunt. We recommend judicious fluid administration preoperatively to avoid a decrease in preload after anesthetic induction resulting from NPO status.

## Intraoperative Management

Maintenance of adequate preload (intravascular volume) and avoiding maneuvers that result in venodilation are key goals. CVP typically is higher in Fontan patients, running 10 to 15 mm Hg with a transpulmonary pressure of 10 mm Hg. Intraoperative management should focus on avoiding increases in pulmonary vascular resistance while maintaining atrioventricular synchrony.

Appropriate ventilator management is based on avoiding increased airway pressure, providing a low respiratory rate, short inspiratory time, longer expiratory time to promote pulmonary blood flow, low PEEP, and low tidal volume (5 to 6 mL/kg). Spontaneous respiration is preferable if possible, as mechanical ventilation increases mean intrathoracic pressure, decreases venous return, decreases pulmonary blood flow, and therefore decreases cardiac output.

Special consideration should be given in laparoscopic procedures. An increase in intraabdominal pressure from gas insufflation decreases venous return (and ultimately cardiac output), increases intrathoracic pressure and mean airway pressure. Keep pressure <10 cm $H_2O$. Maintain intravascular volume. Attempt to avoid hypercarbia which might be difficult with $CO_2$ insufflation. Be aware of high potential for systemic

$CO_2$ embolism, especially in patients with a fenestrated Fontan. As always, if laparoscopy is poorly tolerated, an open procedure should be considered, realizing that postoperative pain control and decreased respiratory effort will complicate postoperative management. Invasive blood pressure monitoring is useful.

Special considerations are also required in pregnancy. Fluid retention leads to atrial distension which leads to arrhythmias. Heart function in pregnant patients with a Fontan circulation deteriorates throughout pregnancy.

## Complications

There are a number of possible complications in a Fontan patient**. They are generally fairly serious.**

Thromboembolic and bleeding events can be quite threatening. These patients are usually anticoagulated, but still may be prone to pulmonary embolism and strokes. Some Fontan circulation includes a fenestration between the extracardiac conduit and the right atrium to provide a "pop off" for right to left shunting. It is possible to have an embolism to coronary and cerebral circulation. The right atrium is typically dilated, especially in fenestrated Fontans, resulting in frequent arrhythmias and the need for a pacemaker. All pacemakers should be interrogated prior to induction.

Protein losing enteropathy (PLE) develops in most Fontan patients as time progresses. The only curative treatment is a heart transplant. PLE results in plastic bronchitis, pleural effusions, peripheral edema, and ascites. Protein losses can result in abnormalities in coagulation, immune function, and other metabolic processes.

Hepatic dysfunction correlates directly with a reduced cardiac index, bradycardia, and venous congestion. Hepatomegaly, increased bilirubin, and decreased total protein are often present. In addition, late findings of cirrhosis and its sequelae may be present. Adult Fontan patients have a 50% incidence of renal dysfunction with severe reductions in the glomerular filtration rate in 15% of patients. Medication administration should be adjusted accordingly.

Residual aortopulmonary collaterals can increase the volume load upon the single ventricle while pulmonary arteriovenous malformations cause intrapulmonary shunting and severe systemic oxygen desaturation. Both can be effectively occluded by preoperative coiling during cardiac catheterization.

### TAKE HOME POINTS

- Single ventricle heart patients typically have undergone palliative staged operations culminating in the Fontan operation.
- In Fontan physiology, venous blood returns to the lungs passively and is dependent

on the transpulmonary gradient.

- Anesthetic management of these patients must include maintenance of intravascular volume for adequate preload, avoidance of increases in pulmonary resistance, and appropriate ventilator management.
- Special considerations should be given in laparoscopic procedures and in pregnancy.
- Fontan patients are at risk for long-term morbidity including coagulation problems, protein losing enteropathy, hepatic and renal dysfunction, as well as residual cardiac defects.

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# Anesthesia for Kids and Neurotoxicity: You Are Going to Be Asked, So Don't Be Surprised and Don't Act Uninformed

Emily Olsen, MD, and Ansgar M. Brambrink, MD PhD

Your friend calls. Her 18-month-old daughter has a reducible umbilical hernia that was noticed by her pediatrician. They went to see a surgeon who discussed the pros and cons of surgical repair. She asked the surgeon whether it is safe for her to receive anesthesia at this age and was reassured. Your friend wants to know what you think about the risks of anesthesia, because she has been looking on the internet and found something about anesthesia affecting the learning potential of kids. "It's a hot topic," you say. "Let's talk about what we know and what we don't know about this issue."

Every anesthesia provider should have some familiarity with the topic of anesthesia-associated neurotoxicity, as this concept has now moved from scientific journals to the mainstream media. You are likely to encounter this subject in a similar way when it is brought up by a patient's family.

## What Is the Big Deal?

In the late 1990s a group of scientists based at Washington University were investigating the effects of fetal drug exposures (in the context of maternal drug use). They showed that pregnant rodents exposed to various N-methyl-D-aspartate (NMDA) receptor antagonists or gamma-aminobutyric acid (GABA) receptor agonists, such as ethanol and phencyclidine (PCP), had offspring with brain damage. They then asked whether exposures to clinically used anesthetics could cause the same sort of damage. Take ethanol, for example; this drug acts both as an NMDA antagonist and a GABA agonist. It is widely known that prenatal exposure to ethanol during brain development can cause cognitive deficits and a neurobehavioral disorder (fetal alcohol syndrome). Most anesthetic agents work via GABA or NMDA receptor mechanisms. Could they also be associated with cognitive deficits and specific neurobehavioral disorders if

children are exposed while their brains are still growing?

We know that brain development is an intricate process, one involving growth of new neurons and glia along with careful pruning of cells by the process of apoptosis (programmed cell death). Normal brain growth is essential for normal neurodevelopment. The period of brain development marked by a rapid increase in cells with concomitant pruning is called the "brain growth spurt." It is paralleled by rapid synaptogenesis creating and further expanding physiologic brain networks. In humans, the "brain growth spurt" period occurs from about mid gestation to age 3, and peaks around the time of birth (at term). This period is thought to be a vulnerable time, where the brain may be particularly sensitive to toxicity. Unfortunately, it is not uncommon for kids of this age range to require surgical or diagnostic procedures involving anesthesia.

## Experimental Literature

The experimental literature has grown extensively in recent years. Carefully controlled animal studies consistently demonstrate brain damage from anesthesia exposure when these animals are exposed during their "brain growth spurt" period. These studies include various doses and lengths of exposure, in different models ranging from nematodes to rodents and monkeys, and including all the major modern anesthetics (isoflurane, desflurane, sevoflurane, nitrous oxide, ketamine, propofol, and several benzodiazepines and barbiturates). Studies have demonstrated that the resulting brain damage involves apoptosis of neurons (gray matter) and oligodendroglia (white matter), as well as changes in synaptic density and axonal viability. Several studies have demonstrated functional deficits in learning and memory that last into adulthood.

## What About Humans?

The question remains whether this type of injury exists in human infants and kids. We can infer that there must not be an obvious clinical injury when our pediatric patients receive anesthesia, otherwise such injury would be readily apparent. However, with the current amount of available experimental evidence, we cannot be sure that there isn't a more subtle injury. If this injury does exist, then we may be able to do something about it like find neuroprotective strategies or identify "safer" anesthesia regimens. Figuring out whether this brain damage occurs in humans is very tricky though. For obvious reasons, one cannot conduct a randomized clinical trial where some kids get anesthesia for their surgery while some do not. Similarly, one cannot give anesthesia to kids for no reason. The currently available clinical studies involve retrospective reviews of major databases (e.g., Medicaid, regional birth cohorts) or prospectively obtained data originally obtained for different purposes (e.g., prenatal ultrasound exposure). This

literature gives mixed results. Some studies show an association between anesthesia exposure and cognitive deficits, poor academic performance, specific language deficits, and/or specific neurologic syndromes like Attention Deficit Hyperactivity Disorder (ADHD), while others show no such associations. The conclusions one can draw from such studies are limited because of their observational and often retrospective designs, among other study specific limitations. For example, how can we be sure that any cognitive changes are not from the surgery itself, the condition requiring surgery, or because the child is treated differently by their guardians/teachers because they were sick?

## What Now?

SmartTots (Strategies for Mitigating Anesthesia-Related NeuroToxicity in Tots) is a partnership between the FDA and International Anesthesia Research Society (IARS), which was formed to support further research in this field. Their website (smarttots.org) is an excellent resource for providers and patients.

There are several large-scale prospective clinical trials currently running including: the Pediatric Anesthesia NeuroDevelopment Assessment (PANDA), Mayo Safety in Kids (MASK), and General Anesthesia and Apoptosis Study (GAS). One can read more about these at smarttots.org or within the authors' review cited below. Each study involves various anesthesia exposures followed by prospective neurocognitive testing. These clinical studies could significantly improve our understanding of the human relevance of anesthetic neurotoxicity. In parallel, basic science studies are essential to model the clinical scenario, identify mechanisms and biomarkers of the injury, and test protective strategies.

### TAKE HOME POINTS

- There is convincing evidence in animal models that anesthesia causes brain damage in developing brains.
- Anesthetic neurotoxicity is an emerging concept in the world of pediatric anesthesiology based mostly on retrospective clinical studies; ongoing prospective studies may provide important new insights when completed.
- At this point, there is not enough evidence available to suggest a change in practice but this may change as more data become available. The Food and Drug Administration has issued a practice statement that has been endorsed by many medical subspecialties (www.smarttots.org). Future revisions will likely be issued based on the scientific progress in the field in order to guide the clinician in their daily practice.

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# Double Down on Pediatric Airway Equipment

Eugene Lee, MD

Pediatric patients come in a variety of sizes, from a 500-g neonate to a 100-kg teenager. Even among patients of the same size and weight, airway sizes can vary unpredictably. One must be prepared for a variety of airways and have the appropriate equipment readily available on the pediatric anesthesia cart.

**Anatomic differences between the pediatric and adult airway include a proportionally larger head and tongue, narrow nasal passages, an anterior and cephalad larynx (at vertebral level of C4 vs. C6 in adults), a long epiglottis, slanted vocal cords, and a cone-shaped larynx with the narrowest point being at the cricoid cartilage. Infants are obligate nose breathers and the upper airway is relatively more prone to collapse.**

The relatively larger head and prominent occiput places the head in a naturally flexed position when positioned supine. It is helpful to elevate the shoulders with a roll which lets the head extend back slightly on the shoulders. This position optimizes the airway for mask ventilation and laryngoscopy. It also allows easier access to the neck if external laryngeal or cricoid pressure is required.

Several laryngoscope blades should be available prior to induction. Prominent adenoidal and tonsillar tissue can obscure visualization of the larynx and a curved blade can sweep the tongue out of the way to improve the view. However, with the larynx anterior and cephalad, the use of a straight blade can greatly aid in intubation. A straight Miller blade can be helpful in picking up the epiglottis which obscures the view of the larynx. This is especially helpful in infants.

Patients may present as a difficult mask airway after induction of general anesthesia. Oral and nasal airways are quite useful and should always be readily available in a variety of sizes. The appropriately sized oral airway should reach from the angle of the mandible to the corner of the mouth. Nasal airways should not be so long that they enter the esophagus. A laryngeal mask airway (LMA) in the appropriate size is a very useful backup if a mask airway is difficult or intubation is unexpectedly difficult. **LMAs have become a mainstay in managing difficult airways in children, much as in adults.** There are a number of syndromes that are associated with difficult direct laryngoscopy.

Having oral and nasal airways and LMAs available can aid with ventilation until a backup plan can be established. Different sized orogastric or nasogastric tube nearby can help manage gastric distension from aggressive ventilation.

If difficult mask ventilation or intubation is expected or encountered, having a video laryngoscope as a tool is becoming the new standard for airway management. Video laryngoscopes provide indirect laryngoscopy and display the glottic opening on a video monitor. In the hands of experienced users, it can markedly improve the view of the glottis and increase the ability to secure an airway. There are several video laryngoscopes that are small enough for pediatric use, with the Glidescope and Storz being the most popular.

One must consider several issues when picking endotracheal tubes (ETT) in pediatric patients (Table 198.1). The ETT must be large enough to permit spontaneous or controlled ventilation but not so large as to damage the trachea. Selecting the largest tube that will enter the patient's trachea will decrease resistance, lessen the likelihood of plugging, allow the passage of suction catheters, and lessen the chance of airway aspiration. Too large of an ETT can cause tracheal damage when the pressure of the ETT against the wall of the trachea exceeds the capillary pressure of the mucosa. This pressure is believed to be 25 to 35 mm Hg in adults, but no values are available for children. Since the cricoid cartilage is the narrowest point of the airway in children and the only complete tracheal ring, mucosal trauma from placing too large an ETT usually occurs here. This can result in postoperative mucosal edema and swelling which presents clinically as stridor, croup, airway obstruction, and increased work of breathing. According to Poiseuille law:

$$R = \frac{8lv}{\Pi r^4}$$

**R is resistance, l is length (of the airway), v is gas viscosity, and r is the radius (of the airway).** Therefore, small changes in airway radius lead to large changes in airway resistance. The appropriate size of ETT can be estimated by a formula based on age: **4 + age/4 = ETT size (mm ID)**. Another way of estimating ETT size is by the formula Body Length in centimeters/20. One should always have at least three different sized endotracheal tubes available; the tube you think is the correct size and a tube 0.5 mm ID larger and one 0.5 mm ID smaller. Correct size is confirmed by easy passage of the ETT and a gas leak at 15 to 25 cm $H_2O$. No leak indicates an oversized tube that should be replaced, while an excessive leak may make ventilation difficult, require excessive fresh gas flows and pollute the operating room. Traditionally, uncuffed ETTs have been the tubes of choice for children under 8 years of age. This was because the funnel-shaped larynx resulted in a natural seal at the level of the cricoid ring and the concern

that a cuffed tube would require a small ID ETT, hence more resistance. Practitioners are also concerned that excessive cuff pressures can cause mucosal damage. Cuffed ETTs are available in pediatric sizes and have a number of advantages. They allow for an "adjustable fit," hence fewer tubes changes to get the right size. A better seal allows higher inspiratory pressure in children with reduced lung compliance. The better seal also results in less leak, reduced fresh gas flows, less operating room contamination, and a reduced risk of aspiration. In order to avoid tracheal damage a number of precautions should be taken. The initial choice of tube size should be at least one-half size smaller than that for an uncuffed tube. The tube should be placed so that the cuff is distal to the cricoid ring. The cuff pressure should be monitored to make sure it is less than 25 to 30 cm water pressure and the cuff should be inflated no more than is necessary to prevent a leak at the patient's peak inspiratory pressure.

**Table 198.1 ■ Estimates for Use in Placing Pediatric Airway Devices**

| Airway Device | Size and Depth Estimate |
|---|---|
| Nasal airways | Best estimate is a tube that extends from the ala nasi to the tragus of the ear |
| Oral airways | Best estimate is a tube that extends from the lips to the angle of the mandible |
| Endotracheal tube size | Uncuffed: 4 + age (years)/4 |
| | Cuffed: 3.5 + age (years)/4 |
| | Premature infant: 2.5–3.0 |
| | Term infant: 3.0–3.5 |
| | Depth at lip: 6 plus the weight (kg) for infants weighing from 1 to 4 kg = depth in cm at the lip (e.g., for a 2-kg infant, 2 + 6 = 8 cm at the lip); for older infants and children, roughly three times the size of endotracheal tube placed = the depth in cm at the lip |
| Laryngoscope blades | Premature infant: "0" Straight Blade (Miller) Term infant: "1" Straight Blade Toddler: "0"–"1" Robert Shaw or "2" Curved (Macintosh) Blade |
| | Older children: 2–3 curved or straight blade, |

| | |
|---|---|
| Laryngeal mask airways | depending on user preference and patient size<br>Up to 5 kg: 1<br>>5–10 kg: 1.5<br>>10–20 kg: 2<br>>20–30 kg: 2.5 |

Correct depth of ETT placement can be estimated by the formula: **12 + Age (years)/2 = depth of tube (cm) at the lip.** Another easy rule of thumb is: depth at the lip is equal to three times the size of the tube. One can also intentionally place the ETT into the right main-stem bronchus and slowly withdraw until breath sounds are equal.

The use of a stylet is frequently not needed for routine intubations in older children. Stylets should be malleable and soft, with a flexible tip in order to avoid airway trauma. There should be different sized stylets immediately available. The use of smaller and flimsier endotracheal tubes along with a more anterior and cephalad airway makes stylets useful in difficult intubations or patients with abnormal airway anatomy.

Because babies can desaturate so quickly, there is not much time to look through your cart for airway equipment. Having a little foresight and preparing your anesthesia cart with the equipment you plan to use and equipment you think you might use will increase patient safety and save a lot of stress when manipulating the pediatric airway.

## TAKE HOME POINTS

- One of the most important things when dealing with the pediatric airway is to understand the anatomic differences.
- Don't assume that you won't encounter a difficult airway—it is not rare to have difficulties both in the mask airway and in intubation.
- Always make sure you see the intubation and airway equipment you plan to use AND the equipment you think you MIGHT use.
- Shall we say it one more time? It is a mistake to assume that the pediatric airway is generally not that big of an issue.
- Study and know the size and depth estimates associated with the use of the most common pediatric airway devices in the table above.

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# Optimizing Bag Mask Ventilation and Direct Laryngoscopy in Children

William Scott Jones, MD and Robert Scott Lang, MD

Airway management in children differs significantly from that in adults. Both mask ventilation and direct laryngoscopy are associated with challenges that can be minimized by an understanding of the anatomy, physiology, and correct technical skills applicable to pediatric airway management.

## Key Anatomic Differences Between Children and Adults

- Large tongue relative to oropharynx
- Large occiput
- Underdeveloped shoulders
- Cephalad larynx
- Epiglottis is narrow and omega-shaped
- Downward slanting vocal cords

## Optimizing Bag Mask Ventilation and Mask Fit

Effective bag mask ventilation in children requires excellent technique. An adequate seal between the mask and face is ensured by maximizing contact with bony structures. The top of the mask should contact the bridge of the nose with the bottom in contact with the mandible. In small children and infants compression of the nasal passage by the mask can be a source of difficult or inadequate mask ventilation. Following proper mask position on the face, the mandible should be lifted up to the mask as opposed to pressing the mask onto the face. Mask position should be maintained with the operator's hand on the edge of the mandible while minimizing compression of midline submental soft tissue which can impede ventilation.

## Ventilation

Anatomic features that limit air movement in children are primarily twofold. First, a

relatively large tongue can collapse posteriorly into the oropharynx and obstruct ventilation both via the oral and nasal passages. A jaw thrust displaces the tongue anteriorly to minimize this effect. Second, pharyngeal structure collapse can be countered by maintaining continuous positive airway pressure during ventilation (CPAP). CPAP is achieved by an effective mask seal, partial closure of the adjustable pressure limiting valve in the airway circuit, and pressure on the bag by the operator's hand.

## Airway Adjuncts

Both oropharyngeal airways (OPAs) and nasopharyngeal airways (NPAs) can act as useful adjuncts to aid bag mask ventilation. Both of these devices displace soft tissue and provide a patent conduit for ventilation. Appropriate OPA size can be estimated by measuring the distance from the front teeth to the base of the tongue. An improperly sized OPA may obstruct ventilation by posterior displacement of the tongue, mechanical obstruction, or act as a stimulus for laryngospasm. Care should be taken to avoid trauma to the palate during insertion. The relatively common practice of inverting an OPA to facilitate insertion, as in adult anesthesia, may cause damage to the hard palate in children. The use of a tongue depressor is a preferred method of insertion. NPA size can be estimated by measuring the distance from the tip of the nose to the auditory meatus. The NPA should be lubricated before insertion to limit trauma to the nasal turbinates. NPA use should probably be avoided in the setting of choanal atresia, coagulopathy, or trauma involving basilar skull fracture. Following cleft palate repair, blind insertion of an OPA or NPA is typically contraindicated, unless performed under direct vision by the surgeon prior to emergence to avoid potentially catastrophic disruption of the repair.

## Optimizing Direct Laryngoscopy

## Equipment

Laryngoscopy equipment for children is smaller than that used for adult airway management. While the laryngoscope blades are necessarily smaller, a smaller handle may also be beneficial. A variety of handles and blade sizes should be available.

## Positioning

Careful positioning is important prior to attempting direct laryngoscopy (DL) in children. A large occiput and tongue, a cephalad larynx, and a narrow epiglottis are anatomic features that can make DL challenging. The classic sniffing position is not always achieved with a head support, neck flexion, and head extension. A larger occiput often allows one to omit a head support in smaller children and infants. Instead, a

shoulder roll often improves laryngoscopic view. Table height can also play a role in successful airway management. Some practitioners may prefer a lower table height to allow for a sitting position during laryngoscopy. This may be beneficial during laryngoscopy to facilitate visualization, as it allows them to look in a more upward direction toward the more cephalad larynx.

## Laryngoscopy

A cephalad larynx and narrow, omega-shaped epiglottis are two additional anatomic features that can make laryngoscope blade positioning challenging. The hyoid bone in children (newborns to 2 years) is at the level of C2–3. The larynx is at the C3–4 level in younger children compared to C5–6 in adult sized patients. This decreases the distance from the larynx to the base of the tongue, resulting in a more acute angle between the planes of the tongue and glottic opening. This anatomic feature makes the straight blade a preferred choice for infants and young children.

The tongue can also be problematic during DL by inhibiting the operator's line of site to the larynx. Although the tongue is often easier to displace with a curved blade in adults, straight blades are commonly used for pediatric DL. The paraglossal approach to laryngoscopy results in lateral tongue displacement with minimal posterior tongue and epiglottis displacement. Straight designs with a wide blade such as the Phillips or Wis-Hipple are very effective. Regardless of blade choice, it is important to control the tongue by displacing it from the operator's line of sight.

There are two techniques commonly used for visualization of the larynx with a straight blade. First, while displacing the tongue aside, the blade may be advanced and airway structures identified until the larynx is in view. The epiglottis is then lifted with the tip of the blade until the vocal cords are visualized. Alternatively, the blade may be carefully advanced into the esophagus and slowly withdrawn until the larynx and vocal cords are visualized. One should use caution before employing the second technique in the setting of foreign body, pharyngeal pathology, or esophageal pathology.

### TAKE HOME POINTS

- Though there are some similarities between the child and adult patient, key differences can be troublesome if not understood. To optimize airway management, one must:
  - Use age- and size-appropriate mask and laryngoscopes
  - Be able to utilize appropriate airway adjuncts during mask ventilation
  - Understand key differences in airway anatomy between children and adults and their implications to positioning and laryngoscopy

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# Why You Should Expect Hypoxemia During Induction and Emergence of the Pediatric Patient and What to Do About It

Andrea M. Johnson, DO, Kirk Lalwani, MD FRCA MCR, and Michael Stella, MD

The "blue baby" is one of the most urgent and potentially disastrous complications an anesthesiologist may face. The term describes the rapid oxygen desaturation of a child, usually occurring at induction or upon emergence of anesthesia. What is especially difficult about this clinical situation is how quickly a pediatric patient can turn blue—it is common to hear the pulse oximeter reading described as "dropping like a stone." Recognition and preparation can be lifesaving. Never be reluctant to call for help when dealing with a "blue baby"—these are challenging situations even for the most experienced pediatric anesthesiologists.

## Physiology and Anatomy

Toddlers, infants, and neonates are all at significant risk for intraoperative hypoxemic events.

**Remember babies are not small adults; they have important differences in anatomy and physiology, particularly in the circulatory and respiratory systems.** In comparison to adults, babies have increased oxygen consumption (6 mL/kg/min vs. 3 mL/kg/min), and decreased functional residual capacity (FRC). Due to the higher ratio of oxygen consumption to FRC, an increased rate of desaturation is often seen when a baby becomes apneic or has an airway obstruction.

Children between the ages of 36 weeks of gestation and 3 to 8 years of age are in the "alveolar stage" of respiratory development. During this stage, secondary alveolar septa form and significantly increase the surface area for gas exchange, the capillary network becomes more robust and true alveoli develop. In addition, neonates and infants have greater chest wall compliance and reduced elastic recoil and compliance of the lung. This immature respiratory physiology creates an increased risk of hypoxemia.

Remember a newborn or infant may also have immature cardiac anatomy and physiology which can further complicate hypoxemia. If hypoventilation occurs, a patent

foramen ovale (PFO) or a patent ductus arteriosus (PDA) will create anatomic shunt, which could cause more rapid desaturation as intrapulmonary and right heart pressures rise. Therefore, anything that causes an increase in pulmonary vascular resistance (PVR) can result in right to left shunting via a PDA or PFO.

Anatomic differences in the young pediatric airway include a relatively larger tongue, pharyngeal hypotonia, and less rigid supraglottic structures. These differences can contribute to a greater chance of airway obstruction. During inspiration pharyngeal obstruction may occur from tongue and pharyngeal soft tissue collapse.

## What Can Go Wrong

A number of events can lead to hypoxic episodes in babies. Hypoxia can be especially common with rapid sequence inductions or in any scenario where preoxygenation failed to occur. However, the most common scenario leading to hypoxia is probably simple respiratory obstruction from pharyngeal relaxation following inhalational induction, sometimes exacerbated by poor mask technique where the fingers apply pressure to the midline of the submental area instead of the **edge of the mandible. This is easily diagnosed before oxygen desaturation occurs by watching the change in chest wall dynamics, as normal inspiratory expansion becomes paradoxical with "dipping" and suprasternal and intercostal retractions.** Applying CPAP by partially closing the APL valve to maintain an airway pressure of 5 to 15 cm $H_2O$ usually relieves this, but in some cases an oral airway may also be needed. A contributory factor for airway obstruction both during induction and emergence is relaxation of the genioglossus muscle which enables the tongue to fall posteriorly and occlude the oropharynx. Another relatively common cause of airway obstruction, especially around the cold and flu season, is laryngospasm. Extubation of patients with reactive airway disease, copious secretions, or during stage II depth of anesthesia can lead to laryngospasm. Laryngospasm can be prevented by thorough suctioning prior to extubation, and avoidance of extubation during the stage II depth of anesthesia. In patients with a history of reactive airway disease, deep extubation can be considered to avoid bronchospasm or laryngospasm.

During emergence, pediatric patients will sometimes involuntarily hold their breath, which can lead to sudden and rapid desaturation. In infants and young children with chronic lung disease related to prematurity, emergence is often a cycle of awakening, coughing, and desaturation that requires hand ventilation to improve oxygenation, following which the cycle repeats until the child is alert enough to remove the endotracheal tube. CPAP helps maintain optimal oxygenation and alveolar recruitment during this phase of emergence in these challenging patients.

Constant vigilance during anesthetic induction and emergence is essential to diagnose

and treat potential airway events early.

## How to Avoid These Problems

To prevent scenarios which can lead to hypoxia always have appropriately sized oral and nasal airways, and a tongue depressor immediately available. Use the proper size and type of laryngoscope blade, and proper head and neck positioning to facilitate visualization of the vocal cords. In patients with copious secretions, consider using glycopyrrolate (10 µg/kg IV) or atropine (10 µg/kg IV) as a premedication to dry oropharyngeal secretions. Preoxygenation prior to intubation and extubation is invaluable, as it can lengthen the time to hypoxia during obstructive or apneic episodes. **To avoid upper airway obstruction, open the mouth and "unstick" the tongue from the roof of the mouth using a tongue blade and consider inserting an oral or nasal airway.** Prior to extubation, suction the airway thoroughly. If emerging from airway surgery, be sure there is adequate hemostasis. If the patient meets extubation criteria, the endotracheal tube or airway device can be removed either while the patient is fully awake, or deeply anesthetized (if performing a deep extubation). Think of extubation criteria as being the "Three G's": Gag, Grimace, and Grasp. Always be prepared to provide positive airway pressure during emergence and during transport to the recovery unit. Succinylcholine (1 to 2 mg/kg IV or 3 to 4 mg/kg IM) and atropine (10 µg/kg IV or 20 µg/kg IM) should always be readily available in the event of an airway emergency.

## What to Do When Hypoxemia Occurs

Despite proper planning, babies may still become hypoxemic. When upper airway obstruction is the cause, it can be treated with an oral or nasal airway and jaw thrust with CPAP or positive pressure ventilation. Breath holding is best treated with 100% oxygen and CPAP so that the child receives an assisted breath upon spontaneous inhalation.

Laryngospasm is initially treated with positive pressure ventilation and 100% oxygen. Jaw thrust and temporomandibular joint pressure can sometimes "break" laryngospasm. If this fails, propofol can be administered, and finally succinylcholine and atropine should be used if propofol is ineffective. In the scenario of bronchospasm, the anesthetic should be deepened, and albuterol administered. If attempts to extubate a patient awake fail repeatedly, deep extubation should be considered. With proper preparation and vigilance a "blue baby" scenario can be managed safely.

### TAKE HOME POINTS

- Babies and infants desaturate rapidly!

- Look for signs of respiratory obstruction during inhalational induction before oxygen desaturation occurs.
- Use CPAP and good mask airway technique to prevent airway obstruction.
- Jaw thrust with two hands helps with laryngospasm and airway obstruction and should be used whenever needed.
- Be especially vigilant in children with chronic lung disease or congenital heart disease, particularly if they are susceptible to right-to-left shunting.
- Do not be hasty extubating babies; it is better to wait than to deal with laryngospasm and profound hypoxia!
- Don't hesitate to call for help when dealing with a blue baby situation.

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# Why Air Bubbles and Air Emboli Can Be So Serious in Pediatric Patients and How to Safeguard Your Patients

Erica P. Lin, MD

The risk of air embolism exists for all patients with central or peripheral venous catheters. The sequelae of intravascular air embolism varies with the volume of air entrained, the rate at which it enters the bloodstream, and whether it is arterial or venous. In pediatric patients with persistent intracardiac and extracardiac shunts, there is also a natural setup for paradoxical emboli. Right-to-left shunting allows blood to bypass the inherent filtering action of the lungs, so emboli arising from the venous system can pass directly into the systemic arterial circulation, where even a small air embolus can have devastating results.

In utero, blood flows in a parallel circuit with respect to the right and left ventricles. The umbilical vein carries oxygen-saturated blood from the placenta toward the heart. The ductus venosus is the first shunt encountered and connects the umbilical vein with the inferior vena cava, allowing roughly half of this oxygen-rich blood to be diverted away from the liver. Within the right atrium, a pressure gradient enables a significant portion of this oxygenated blood to be preferentially streamed across the foramen ovale to the left atrium. This allows the blood with the most oxygen content to be efficiently delivered, via the left ventricle and aorta, to the coronary and cerebral circulations. Right ventricular outflow consists of a mixture of oxygenated blood from umbilical veins plus desaturated blood from the superior and inferior venae cavae. Only 10% of right ventricular blood actually passes into the pulmonary circuit because of high vascular resistance (the combined result of fluid filled fetal lungs and medial muscle hypertrophy in the small pulmonary arterioles). The remaining 90% of right ventricular output is shunted away from the lungs through the ductus arteriosus and into the descending aorta where it supplies the lower body or returns to the placenta via paired umbilical arteries.

The transition between fetal and neonatal circulation occurs primarily in response to changes in resistance throughout the circulatory system. The parallel circulation of the

fetus converts to a series system. Clamping of the umbilical cord eliminates the low-resistance placenta, and systemic vascular resistance increases. Without venous return from the placenta, right atrial pressure decreases. As breathing is initiated, pulmonary vascular resistance falls dramatically resulting in an increase in blood flow to the pulmonary circulation. In addition, higher pulmonary arterial oxygen tension (compared to the relatively hypoxemic fetal environment) contributes to lower pulmonary vascular resistance. Due to remodeling of the pulmonary vasculature, a continued gradual reduction in pulmonary vascular resistance occurs during the first months of life. More blood flow to the lungs translates to greater pulmonary venous return to the left atrium. Elevated left pressure relative to the right atrium facilitates closure of the flap-like foramen ovale. Higher arterial oxygen concentration stimulates closure of the ductus arteriosus. Removal of the placenta also lowers circulating prostaglandin levels, which further facilitate ductal closure. The ductus arteriosus is functionally closed within the first 24 hours after birth, but permanent closure requires thrombosis and fibrosis.

**Because anatomic closure of these alternate pathways does not occur immediately after birth, the shunts can still be reopened in response to physiologic stimulation.** For example, premature infants demonstrate less sensitivity to the effects of oxygen on ductus arteriosus closure. Similarly, the existence and often the pharmacologic maintenance of these shunts are necessary for the survival of infants with congenital heart disease until surgical correction is possible. The drawback, however, is that these shunts provide a route for paradoxical emboli into arterial circulation where entrance into cerebral or coronary circulation. Such emboli can be catastrophic, resulting in permanent neurologic damage, myocardial infarction, and even death.

There are simple measures that can be taken by healthcare providers to minimize the risk of iatrogenic emboli. **Intravenous catheters are an especially frequent culprit, with a high percentage of reported air embolisms attributed to central venous access devices.** Disconnection of the line, fracture of the hub, or a break in the tubing can allow air entry. Medication administration can also introduce air. Common precautions include expelling air from syringe prior to attachment, then holding the syringe upright, aspirating fluid from the proximal intravenous tubing into the syringe, and tapping the syringe before injecting to dislodge any remaining trapped air to the superior aspect of the syringe. Nevertheless, Wald et al. demonstrated in their experimental model that an average volume of 0.02 mL is delivered per injection, even when careful attention is paid to remove all air before mounting syringes onto connecting lines. Special care should always be taken when preparing infusions. **Ideally, fluids should not be prepared in a cold room and then brought into a warm environment.** As the temperature is raised, gas bubbles may form because of reduced solubility, and the size of existing bubbles will increase. This same principle applies to

the infusion of fluids through a warming system. As the solution passes through the warmer, microbubbles can form. As microbubbles emerge from solution, they tend to coalesce into larger bubbles that can be passed to the patient. Studies have shown that higher rates of infusion through warmers correspond with decreased amounts of gas escaping from solution. This is presumably due to the shorter amount of time the solution spends in the warming tubing, which then limits the time for gas to diffuse out of solution. Distally placed bubble traps or a stopcock for aspiration of any collected air have been suggested. Efforts should also be made to remove air from intravenous fluid bags prior to infusion, as there have been case reports of massive air embolism, especially when used with pressurized infusion devices. Other safety measures that can be employed include the use of air-eliminating filters on the infusion tubing sets when appropriate. Infusion pumps with air-in-line sensors should be used for all continuous infusions.

## TAKE HOME POINTS

- The risk of paradoxical air embolism is greater in newborns with transitional circulation and patients of any age with cardiac lesions that allow right-to-left shunting to occur.
- Furthermore, as many as 25% of adults have a patent foramen ovale that can provide a path for paradoxical emboli.
- For these reasons, it is imperative that caretakers always be meticulous in preparing all IV infusion systems. Air emboli into the cardiac or cerebral circulation can have catastrophic consequences in pediatric (or even adult) patients.
- Intravenous lines, especially central venous catheters, pose a significant risk for emboli. Be especially vigilant for disconnections, fractures of the hub, or breaks in the tubing.
- Expel air from syringe prior to attachment, then hold the syringe upright, aspirate fluid from the proximal intravenous tubing into the syringe, and tap the syringe before injecting to dislodge any remaining trapped air to the superior aspect of the syringe.
- Do not prepare infusions in a cold room and then bring them into a warm room.
- Warmers also pose a similar risk as warming fluids allow microbubbles to form as the gas solubility changes.
- It is imperative to room air from IV fluid bags and transfusion products as massive and fatal air emboli can occur.
- “De-airing” is something that experienced pediatric anesthesiologists do constantly and well. Watch what they do and apply it to your own practice, even if your practice is mostly adult anesthesia.

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# Pediatric Fluid Management

Linda Chung, MD and Pilar R. Mercado, MD

Perioperative fluid management in the pediatric population poses many challenges and difficulties to anesthesiologists. Neonates, infants, and children each have distinct and unique physiologic characteristics that can affect fluid requirements. Unfortunately, there is also a scant amount of literature looking at fluid therapy in the pediatric population. Many simplified rules have been adapted to quickly calculate maintenance fluids. In 1957, Holliday and Segar determined that there was a linear relationship between fluid losses and weight. Their data produced the elegant 4-2-1 rule of fluid management that is the foundation of many clinicians' fluid management therapies. However, it was not intended to be used blindly and broadly. It is plausible to say that there is no perfect maintenance fluid or rate, and fluid should be titrated according to the individual needs of the patient. This chapter is intended to provide guidelines to perioperative fluid management.

Proper fluid management is imperative to appropriate patient care. Under-resuscitation can lead to hypovolemia. Giving too much fluid can lead to pulmonary edema, postoperative respiratory complications, and a fluid-overloaded state. Having a thorough understanding of patients' comorbidities (i.e., kidney failure, congestive heart disease, etc.) is also important in determining the amount of fluid a patient should receive.

Preoperative fluid management is complicated mostly by NPO status. In 2009, the ASA released changes in the NPO requirements for children. Based on a review of literature the following recommendations were made:

- Clear liquids: 2 hours
- Breast Milk: 4 hours
- Formula or cow's milk: 6 hours
- Light meal: 6 hours
- Heavy meal: 8 hours

Children coming in for elective surgery are less likely to be hypovolemic after the guideline changes.

Neonates and chronically ill children make up the majority of the inpatient population. Many of these patients have a higher fluid need secondary to increased metabolic demands, comorbidities, and prematurity. Prior to presenting to the operating room, these patients will have received IV fluids for the duration of their fasting interval. However, many will still be under-resuscitated because their increased fluid needs were not met and only maintenance fluid was given. The anesthesiologist should be able to assess the fluid status of a child prior to surgical intervention. Clinical judgment should be based on understanding age-appropriate normal vital signs and physical examination findings that can be associated with a hypovolemic patient (Table 202.1).

Deciding the appropriate fluid to use can be a difficult task. Holliday's original article determined the daily electrolyte requirements infants need by determining the composition of breast and cow's milk. Recommendations include 2 mEq/100 kcal/day of both potassium and chloride and 3 mEq/100 kcal/day of sodium. Theoretically, energy and electrolyte requirements should be met by 5% dextrose with 0.2% normal saline. Glucose-containing hypotonic solutions continue to remain the staple of maintenance fluids for the pediatric population today.

**Table 202.1 ■ Normal Pediatric Vital Signs**

| | Weight (kg) | Heart Rate (beats/min) | Systolic Blood Pressure | Diastolic Blood Pressure | Respiratory Rate |
|---|---|---|---|---|---|
| Premature (<37 wks) | 0.7–2.5 | 120–170 | 40–60 | 21–45 | 50–70 |
| Newborn (>37 wks) | 2.5–4.3 | 100–170 | 50–70 | 40–60 | 40–60 |
| Neonate 1 mo | 3.4–5 | 90–160 | 60–80 | 45–65 | 30–50 |
| Infant (1 mo–1 yr) | 4.5–10 | 80–160 | 70–100 | 41–80 | 25–40 |
| Toddler 1–3 yr | 10–14.5 | 70–110 | 70–110 | 45–85 | 20–30 |
| 3–6 yrs | 14.5–19 | 65–110 | 80–110 | 45–85 | 20–30 |
| 6–12yrs | 19–41 | 60–95 | 94–130 | 45–85 | 20–24 |
| 13 yrs+ | >41 | 60–90 | 94–130 | 60–90 | 12–20 |



Isotonic fluid is usually recommended intraoperatively because fluid losses are generally isotonic (i.e., blood and interstitial fluid). ADH release increases intraoperatively which leads to patients retaining free water, as well as necessitating an increase in electrolyte demand. There have been multiple theories on how to replete

fluid losses incurred while a patient was NPO. Furman et al. describes using the 4-2-1 rule, determining the hourly fluid need, and subsequently multiplying the hours the patient was NPO to determine the fluid deficit. They then recommended replacing 50% of the fluid deficit in the first hour of surgery and the remainder in the next 2 hours.

The vast majority of pediatric cases are short ones, especially bread and butter cases. Therefore, replacing fluid deficits over 3 hours is not plausible. Giving a 10 to 20 cc/kg bolus of fluid at the beginning of the operation usually replaces most of the fluid deficit. If the patient is considered dry or hypovolemic, a 10 to 20 cc/kg fluid challenge is appropriate to assess how intravascularly depleted the child is as well. A quick way to determine the rate of infusion is to multiply the desired volume to be given by 4 or 6. This provides the rate the bolus can be given over 10 to 15 minutes. For example, if the desired bolus is 100 cc; infusing at a rate of 400 cc/hr will provide a 100 cc bolus in 15 minutes.

**Vigilance is key to pediatric fluid management. It is very easy to give neonates and small infants too much fluid in a short amount of time.** For example, a 2-kg neonate only needs 8 cc/hr of maintenance fluid. A patient this size can easily be given too much fluid within minutes if the IV is left open. Having the IV tubing connected to a buretrol or on a pump can avoid giving a child too much fluid as well.

Intraoperative insensible losses must be accounted for in addition to blood loss, maintenance fluid, and NPO deficits. Insensible losses can be difficult to estimate but some estimates

- 1 to 5 cc/kg for minor surgeries
- 15 to 20 cc/kg for major abdominal surgery
- Up to 50 cc/kg for premature infants with NEC

Adding glucose to intraoperative maintenance fluid is also a controversial topic. Hypoglycemia can have significant effects on neonatal nervous system development. However, hyperglycemia can also worsen neurologic function and lead to osmotic diuresis. In the healthy pediatric population with the updated NPO guidelines, hypoglycemia is rare and glucose-containing solutions are no longer recommended. Dextrose is only recommended for patients that are at high risk for hypoglycemia. These include debilitated infants, malnourished infants, premature infants, cases of severe sepsis or burn patients, patients on hyperalimentation, infants with endocrinopathies, and infants undergoing major surgery like cardiac surgery. As with any medical intervention, glucose-containing solutions should be titrated appropriately and blood glucose levels should be monitored closely.

## TAKE HOME POINTS

- Unfortunately, there is a paucity of literature to guide perioperative fluid management in the pediatric population.
- Many clinicians continue to use Holliday's original 4-2-1 rule as a starting point to fluid management and subsequently titrate as clinically indicated. However, here are some clinical pearls to assist in pediatric fluid management:
- **Vigilance is key.** Being aware of how much fluid was given as well as how much is needed is imperative.
- Calculating fluid deficits from NPO status and hourly maintenance requirements will assist in determining fluid deficits.
- Holliday's 4-2-1 rule is still used as a foundation for initially fluid management.
- Giving a 10 to 20 cc/kg bolus at the beginning of a procedure is an appropriate starting point to assess a child's fluid status.

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# Keeping Babies Warm in the Perioperative Period Is Important, Challenging, and at Times Dangerous!

Kathleen A. Smith, MD and Daniel Rosenkrans, MD

Virtually all pediatric patients will become hypothermic in the perioperative period unless measures are taken to maintain normothermia. Hypothermia leads to a variety of complications including delayed emergence, prolonged neuromuscular blockade, platelet dysfunction, increased oxygen consumption, and poor wound healing. Kurtz et al. found that even mild perioperative hypothermia in patients having colorectal surgery increased the risk of surgical site infections by three-fold. As a result of these findings, the Surgical Care Improvement Project (SCIP) was instituted in 2003 to reduce preventable adverse outcomes in surgical patients. One specific measure, SCIP Inf-10, calls for maintenance of normothermia in the perioperative period, and documentation of either active warming or perioperative temperature >36°C. Recently, Scott et al. confirmed that compliance with this guideline was independently associated with reduced risk of hospital-acquired infection, ischemic cardiovascular events, and in-hospital mortality, as well as decreased length of stay. Thus, the anesthesiologist must continuously monitor core temperature, and actively prevent hypothermia and its sequela.

There are a number of reasons for heat loss, which begins with exposure of the patient upon removal of clothing. Radiation is the most important type of heat loss, but convection, conduction, and evaporation also play a role. Most operating rooms are extremely cold, allowing for tremendous heat loss via radiation to the OR environment. Cold surgical prep solutions partially evaporate from the skin, decreasing the body's temperature further. Other evaporative losses occur from surgical incisions and the airway. Volatile anesthetics cause vasodilation, distributing blood to the cutaneous surface where it can participate in heat exchange with the environment. During the first half hour of anesthesia, this redistribution of heat from the core to the periphery causes the temperature to drop 0.5°C to 1.5°C. General anesthesia also impairs normal function of the body's thermoregulatory center—the hypothalamus. Under normal circumstances,

the vessels of the body constrict to conserve heat, while metabolic heat production is increased. Peripheral vasodilation is combined with a 20% decrease in heat production, thus altering the thermal steady state.

Remember that heat loss is directly proportional to surface area. Infants and neonates have a very large surface area to volume ratio, making them particularly prone to hypothermia. In addition, metabolic heat production is a function of mass, so infants are also less capable of producing heat. Infants and neonates do not shiver. They produce heat via nonshivering thermogenesis, which takes place primarily in brown fat. This mechanism of heat production, which continues until 2 years of age, is inhibited by anesthesia and sympathetic blockade.

For the many aforementioned reasons, anesthesiologists often battle intraoperative hypothermia. This has led to the development of various mechanisms that can be used to maintain normothermia during anesthesia. Some of the methods are simple and can be of tremendous benefit. Warming the operating room by 1°C will decrease heat loss by 7%. Passive insulators, such as blankets or plastic bags wrapped around the exposed surfaces of the body may reduce heat losses up to 30%. **An infant's head is a major source of heat loss given its large surface area, and should be wrapped to decrease radiative heat losses.** IV fluids should be warmed during longer cases with greater fluid requirements. One liter of room temperature fluid given to an adult reduces core temperature between 0.25°C and 1.0°C. A similar result is seen in children receiving a comparable volume of unwarmed fluid. Circulating water mattresses are used less often to reduce conductive heat losses. Their effectiveness is limited given that they only reduce the already minimal heat loss from a patient's back. Warming lights, infrared heaters, and warm prep and irrigation solutions may also be of benefit.

Perhaps the most popular means of preventing hypothermia intraoperatively is the forced air warmer. These devices work via convective heat transfer, and depend on a device-skin temperature gradient. As helpful as this device can be, improper use may have an opposite effect. The FDA notes several reports of patient injury resulting from the use of warming hoses alone, not attached to the warming blanket. This so-called "free-hosing" has led to third-degree burns in several patients.

A second pitfall with forced warming devices is unintentional patient cooling when either the skin beneath the blanket or the blanket itself becomes wet as a result of messy surgical prep, irrigation, or body fluids. Little information has been published regarding this phenomenon. We attempted to quantify the degree of patient cooling that can result when this occurs in a small experiment. Skin temperature probes were inserted into three normal saline bags. The bags were placed in a warmer for 30 minutes. Following removal, two bags were placed on underbody warming blankets and covered by plastic drapes. The warming units were turned on. The third bottle served as a control (C), and

was not actively warmed. Warm irrigation fluid (150 mL) was poured onto the blanket of bag W, while bag D remained dry. The temperature of both bag C (control) and W (wet) declined significantly over 50 minutes, while the temperature of bag D (dry) increased. The final temperatures were 34.3°C, 39.4°C, and 34.7°C in bags C, D, and W, respectively. Clearly, the soiled blanket was not only ineffective at heating, but actually cooled the bag of saline significantly.

**We advise that steps must be taken to prevent forced air warming blankets from becoming soiled. This starts with awareness of all personnel, especially surgeons.** A prep job that is sloppy and uses an excessive amount of solution is best avoided. In addition, a plastic sheet is included with each warming blanket. This may be used to make a barrier between the operative field and the blanket itself. This step may reduce the incidence of saturating the blanket, both during the prep and throughout the surgery. If a warming blanket does become wet, it should be removed and, if possible, replaced. If a warmer must be removed, the OR temperature should be increased. This may be an incentive for all OR personnel to be cautious not to allow the blanket to become wet.

Finally, be aware of iatrogenic hyperthermia. Many practitioners, in an effort to prevent hypothermia, overuse warming techniques resulting in hyperthermia. This is not uncommon in dental surgery, for example, where virtually the entire body is covered and no body cavities are exposed. This results in very minimal, if any, heat loss. These cases tend to be long and the child's basal metabolic rate naturally generates heat. If atropine has been given, sweating is reduced, preventing dissipation of this heat and increasing body temperature. In this situation, a forced air warming blanket may actually be used to help cool a febrile patient using the ambient setting.

## TAKE HOME POINTS

- Hypothermia in the pediatric patient is a constant risk. Deleterious effects include delayed emergence, prolonged neuromuscular blockade, platelet dysfunction, increased oxygen consumption, and poor wound healing.
- Compliance with SCIP mandates for patient warming and the documentation thereof has been associated with better patient outcomes.
- Heat loss is directly proportional to surface area, which makes infants and neonates very vulnerable to hypothermia due to their large surface area to volume ratio.
- Babies lose heat via radiation, convection, conduction, and evaporation. Radiation heat losses are the most important.
- Fighting against hypothermia includes warming the room, passive insulation, wrapping the head and exposed body parts, and warning the IV fluids.
- Forced air warmers are both a good thing if used correctly and a bad thing if not.

Never use the hose without the blanket—this technique of "free-hosing" can and has led to third-degree burns.

- Take great care that the warming blanket does not become wet or soiled. It if does become wet, it should be removed and the room temperature increased.
- Ironically, iatrogenic hyperthermia can also be an issue. Be especially vigilant for this in dental cases.
- Overall goal: We want our pediatric patients warm, but not too warm and we need to do it effectively and safely.

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# Pediatric Arterial Access—And the Beat Goes On

Rebecca Hall, MD, Kirk Lalwani, MD FRCA MCR, and Angela Kendrick, MD (Retired)

The indications for arterial access for the pediatric patient are the same as for the adult patient—beat-to-beat blood pressure measurement and arterial blood gas sampling.

Pediatric arterial line placement can be as straightforward as that in an adult, particularly with older children, and no modification of technique is usually required. In these patients, the standard technique of entering the vessel with an angiocath and threading the catheter directly over the needle is usually successful.

**However, in younger children and infants, this technique often fails despite successful arterial puncture. It is typically more difficult to thread the catheter directly over the needle. Modification of technique to a transarterial technique will improve your success rate significantly.**

Two methods are commonly described. In both, careful anchoring of the forearm and slight extension of the wrist with adhesive tape and an arm board will help. Following aseptic preparation of the wrist attempt to locate the artery by palpation to guide skin puncture. It is important to do this accurately with the ball of the finger rather than the tip. In some cases, the artery will be impalpable. In these situations, you have two choices. Tear off the glove fingertips of your palpating hand, sterilize your fingertips with an alcohol swab, and repalpate until the vessel is localized. Alternatively, use an ultrasound machine to visualize the vessel. One could argue that in neonates/infants this should always be a part of your plan, though there is merit in learning how to place these lines in this age group without ultrasound.

Once the artery is punctured and arterial blood is visualized in the angiocath, drive the angiocath right through both walls of the vessel. Now place a suitable guidewire in the lumen of the hub only while very gradually withdrawing the catheter until pulsatile flow appears. Smoothly introduce the guidewire through the catheter. If successful, thread the catheter over the guidewire. If the guidewire does not thread easily try gentle adjustments and rotation of the catheter and the guidewire, which often helps. If no success, it is likely spasm of the artery, or unknown factors and you may have to start all

over.

The other method does not use a guidewire, but instead a saline-lubricated 3 mL syringe. After attaching this to the catheter following transarterial puncture, apply gentle aspiration to the syringe while slowly withdrawing the catheter. Once free flow occurs, simultaneously inject blood from the syringe and change direction to advance the catheter–syringe assembly into the vessel. In this technique it is essential to make a small nick in the skin with an 18G needle tip to allow smooth passage of the catheter without resistance and buckling, since it has no wire in it to stiffen it.

Combined catheter and guidewire kits (Arrow) can also be used for placement.

Radial arteries are preferred. If unsuccessful, dorsalis pedis and posterior tibial are often easy to palpate. If none of these are suitable, femoral arteries are the preferred site, followed by a surgical cut down.

## Site Selection

Radial arteries are preferred for pediatric arterial lines. The radial artery is not an "end artery" to the hand because of the collateral circulation offered by the ulnar artery. However, it is estimated that 10% of pediatric patients do not have good collateral flow to the hand. A modified Allen test (return of normal hand color within 6 seconds following release of ulnar artery after occlusion of both radial and ulnar arteries) has been used to help identify patients without significant collateral flow to the hand. **If your patient fails the Allen test, do not even think about placing an arterial line in that little hand.** But also remember, even if your patient "passes" the Allen test that this test has not been shown to have predictive value to forecast which patients may develop hand ischemia after radial cannulation. Other vessels used for arterial access for the pediatric patient include the dorsalis pedis, the posterior tibial, and the femoral. The dorsalis pedis and posterior tibial arteries are often easy to palpate. If none of these are suitable, then femoral arteries are the preferred site, followed by a surgical cut-down.

Catheters (22G or 24G) are appropriately sized to reflect the size of the target vessel. Ultrasound guidance may be utilized to identify and cannulate the small arteries of the pediatric patient and we recommend that all pediatric practitioners acquire and maintain skills in the adjunctive use of ultrasound for line placement.

You may occasionally see an umbilical catheter if you are caring for a sick neonate or working in the NICU for any reason. Umbilical catheters are thought to have been an innovation of Dr. Virginia Apgar and they have great efficacy in little patients for whom other types of arterial access are very problematic. They can generally be safely used for the first 5 to 7 days of life and can stay in place for about 5 days. In addition to blood pressure monitoring and arterial blood gas sampling, they can also be used for angiography and exchange transfusion. Insertion of the catheters is a somewhat involved

two-person procedure and it is unlikely that you will be placing them in the operating room. The most important thing to remember for the general practitioner is that umbilical artery catheters are not peripheral arterial lines as the umbilical arteries are a direct extension of the internal iliac arteries and they are usually placed so that the catheter tip is in the aorta. When caring for a patient with an umbilical catheter, find out whether the catheter is above or below the diaphragm, as higher catheters have a lower incidence of vascular sequelae. Umbilical artery catheters are contraindicated in neonates with abdominal wall malformations such as omphalocele and certain intraabdominal pathologies such as peritonitis and necrotizing enterocolitis. If an umbilical catheter is in place and you suspect peritonitis, necrotizing enterocolitis, or suspect or can confirm vascular compromise to the lower extremities, buttocks, or kidneys, seek an immediate consultation with the most senior pediatric anesthesiologist, pediatric surgeon, or pediatric intensivist you can locate.

## Complications of Arterial Access in Pediatric Patient

Mechanical complications include injury to the vessel, thrombosis of the vessel, and embolization. Nerve injury can also result from puncture of a nerve, or as a result of hematoma formation near the nerve. Thrombosis is estimated to occur in 1% to 4% of cannulations (about 5% for umbilical catheters). Complications increase with the use of larger catheters and prolonged use. Distal perfusion needs to be checked every 8 hours, observing capillary refill, skin temperature, and color. If poor perfusion is detected, the catheter should be removed immediately and the extremity monitored closely for the return of adequate perfusion.

### TAKE HOME POINTS

- For older children, arterial access is quite similar to adults, although generally a smaller catheter is used.
- Like adults, radial arterial lines are preferred for all children in which they can be safely done.
- Move quickly to a transarterial approach, using a saline-filled syringe to apply back-pressure to the artery, if you do not get a guidewire-assisted line on the first try.
- Use ultrasound if available!
- Dorsalis pedis, posterior tibial, and femoral arterial lines are possible, followed by a cut-down if necessary.
- An umbilical arterial line is not a peripheral arterial line. Remember always that the tip of that catheter is sitting right in the middle of the patient's little aorta. Check intermittently but repeatedly for signs of ischemia in the lower extremities and

buttocks.

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# Pediatric Regional Anesthesia—The Karma of Caudals

Eva J. Waller, MD and Elizabeth Ross, MD

Caudal epidural anesthesia is an established technique that remains underutilized. The technique is reliable and relatively easy to do, with a low rate of complications.

We suggest that it is worthwhile for practitioners of pediatric anesthesia, even occasional practitioners, to take the time to become and remain proficient in doing caudal epidurals. This technique will add to your anesthetic practice because it so readily provides elegant and effective postoperative pain relief as well as adjunctive intraoperative anesthesia.

## Indications

Caudal epidurals are easiest to do and most indicated in kids below the age of 5 years or 20 kg. They are occasionally done in children as old as 8 years of age. The technique can be used to supplement general anesthesia during surgery and for postoperative analgesia in pediatric patients undergoing a variety of inguinal and genital procedures such as repair of hydrocele or hypospadias, circumcision or circumcision revision, open repair of hernias, and lower-extremity surgeries, including fracture repair. **If you are in doubt about an indication, just remember that they are essentially the same as for lumbar epidurals.** Epidural caudal catheters are also generally placed for more extensive procedures such as ureteral implant surgery or major lower abdominal surgeries when the postoperative pain issues will be managed by an acute pain team. However, the technical ease of the single-shot caudal epidural places it well within the practice parameters of less-experienced pediatric anesthesiologists and anesthesiologists who provide care to pediatric patients only occasionally.

## Contraindications

The complications of caudal epidurals include known or suspected anatomic abnormality, infection around the sacral hiatus, sepsis or known bacteremia, coagulopathy, increased intracranial pressure, uncorrected hypotension, and lack of

patient assent and/or parental consent.

## Risk-Benefit Ratio and Parental Consent

The discussion with the parents should highlight that the epidural can provide wonderful postoperative pain management to a small child. However, it is essential that both the sensory and motor block be fully discussed with the parents, including need for close supervision of the child at home to prevent falling and accidents and to provide reassurance for the child. Similarly, an age-appropriate discussion should be held with the patient as well. **Always** tell the child that her legs will feel "wobbly," "tingly," and so forth and **never** use the word "paralyzed," either to the parents or to the patient.

## Anatomy

We think this is where the occasional practitioners first tend to get a little intimidated since the sacral anatomy is just not as familiar to us as the lumbar anatomy. However, the pediatric anatomy is uniquely advantageous for the caudal approach to the epidural space. **Remember that the caudal epidural space is just the continuation of the lumbar epidural space with no spinal cord to get in the way or cause complications.** The components of the caudal space are the cauda equina, the vascular plexus, and epidural fat. Before the age of 1, the caudal extent of the dura and spinal cord ends at S3–4 and this anatomical level moves cephalad as the child grows.

The topography of the fused sacral vertebrae and the bony structures of pelvis is complicated and somewhat confusing in diagrams and photographs, especially when rotated into the lateral point-of-view of the operator. We find that it is easier to teach and review the anatomy of the caudal anesthesia using surface line drawings and surface palpation and triangulation of three bony landmarks—the posterior superior iliac spines and the cornu of the sacral hiatus. The other way to find the sacral hiatus is to palpate the coccyx and then slid your fingers in a cephalad direction. The sacral hiatus is always above the intragluteal fold and is covered by the sacrococcygeal ligament. Another anatomical relationship that should be appreciated is the ventral proximity of the bowel and gastrointestinal tract.

## Technique

Caudal epidural anesthesia is always done with the patient under general anesthesia, either at the start or end of the case. The patient should be placed in lateral decubitus position (left lateral for right-handed anesthesiologist and right lateral for left-handed anesthesiologist), with hips and knees flexed to help spread the gluteal muscles away from the sacral hiatus, but not overflexed. Some practitioners will ask for a little bit of traction on the top leg. Using strict aseptic technique, a 22G intravenous catheter or

blunt 22G needle is inserted at the sacral hiatus approximately 45 degrees to the skin until a "pop" is felt, which indicates penetration of the sacrococcygeal ligament. The angle of the needle should then be lowered before advancing a few more millimeters into the caudal epidural space, and the catheter threaded-off if used. If you are using an IV catheter as your needle, the ability to easily slide the cannula of the needle more or less indicates correct placement; difficulty doing this usually indicates subcutaneous placement. **If you don't access the caudal epidural space on the first try, most likely your initial angle of approach was too shallow.**

Most experienced practitioners would make a second attempt. If that fails, cancel the block and adjust your anesthetic plan accordingly.

Gentle aspiration is necessary to check for blood or cerebrospinal fluid. An initial test dose of 0.1 mL/kg of local anesthetic (not more than 10% of total dose) with 1:200,000 epinephrine should be used to exclude intravascular placement (see below). Resistance to injection should be minimal. Any resistance strongly suggests that the needle tip is not in the epidural space.

The placement of a caudal epidural block should be smooth and fairly quick, which should allay the fears of the surgical team about undue delay. An experienced operator will typically only take about 5 minutes to place the block. Ten minutes is about the right amount of time for someone who is not as experienced. If your caudal epidural blocks are taking longer than this, watch and study the techniques of your more experienced colleagues, but of course don't ever take short cuts or compromise the time required for an aseptic technique.

Drugs: For single shot caudal epidural injection, long-acting local anesthetics such as bupivacaine 0.125% to 0.25% and ropivacaine 0.2% are typically used. The volume of local anesthetic depends on the desired blockade level. For example, 0.75 mL/kg is adequate for a perineal procedure, 1.0 mL/kg is needed for an inguinal level, and 1.0 mL/kg for an umbilical level block. The maximum volume is 1.25 mL/kg, which will give you a low thoracic level in an infant. The maximum recommended dose for bupivacaine is 2.5 mg/kg and for ropivacaine is 3.0 mg/kg. Common adjuvants to caudal epidural injections include epinephrine, clonidine, and narcotics such as morphine and fentanyl. Epinephrine (5 μg/mL) prolongs the duration of caudal bupivacaine, and is useful to detect inadvertent intravascular injection. Clonidine, an α-2 agonist, also prolongs the duration of blockade with minimal side effects. The appropriate dose is 1 to 2 μg/kg. Do not use more as hypotension, bradycardia, and excessive sedation can be seen with higher doses. Opiates such as morphine and fentanyl can be useful supplements to caudal anesthesia, but side effects such as pruritus, urinary retention, and respiratory depression are common. **The caudal epidural adjuvants should be used only if the patient is going to a postoperative monitored bed.** If the patient is to be

discharged home, then use only your local anesthetic of choice. Recently, dexmedetomidine (another α-2 agonist similar to clonidine but with greater affinity for the α-2 receptor) at 1 to 2 μg/kg has been shown to prolong caudal block duration with few side effects. Dexmedetomidine has not been studied as extensively as clonidine and is not currently not part of accepted practice for caudal epidurals.

## Complications

Dural puncture: Unintentional dural puncture can lead to total spinal. Symptoms include apnea, blown pupil, hypotension, and unresponsiveness. Younger children (under 6 years old) usually do not exhibit unstable hemodynamics due to an immature sympathetic system and greater centralization of their intravascular space. Treatment is supportive and includes airway management, ventilation/oxygenation, and circulatory support with fluids and vasopressors as indicated.

Intravascular injection: Intravascular injection is the most common serious complication of caudal anesthesia. Using a test dose and looking only for heart rate changes is not a sensitive indicator of intravascular injection in anesthetized children. Changes in EKG morphology, especially peaked T-waves and broadening of the QRS complex, are more sensitive indicators of intravascular (or intraosseous) injection. A caudal block should **NEVER** be placed without continuous EKG monitoring. Even after an initial negative test dose, the remaining local anesthetic should be given incrementally, looking for EKG changes between each dose. Local anesthetic toxicity manifests as seizures, hypotension, arrhythmia, and cardiovascular collapse. Treatment includes airway management, circulatory support, and intralipid. An initial bolus of 1.5 mL/kg should be given, followed by an infusion at 0.25 mL/kg/min. Cardiac toxicity is particularly severe with bupivacaine and may require prolonged supportive therapy, including cardiopulmonary bypass, while intralipid therapy is provided.

Intraosseous injection: Intraosseous injection can lead to systemic toxicity similar to intravascular injections. The thin cortical bone of the sacrum is easily penetrated in pediatric patients. Treatment is the same as for intravascular injection.

Puncture of the surrounding gastrointestinal system: this is a rare but potentially devastating complication, due to the possibility of infection of the epidural space. Discontinuation of the block and procedure is warranted with immediate consultation to the surgical and infectious disease services.

### TAKE HOME POINTS

- The caudal epidural is a great modality to provide postoperative pain relief and decrease intraoperative anesthetic requirements. The one-shot technique is very

accessible to the occasional provider of pediatric anesthesia.

- Get both consent from the parent and assent from the patient and always carefully describe both the sensory and motor blockade and the necessary postoperative precautions.
- In children, caudal epidurals are always done in anesthetized patients, in the lateral position. Flex the hips and knees, but not too much.
- If you can't get the "pop" of the sacrococcygeal ligament, the angle of the needle is probably too shallow. Also, if you start in approximately the right area, there is very little damage you can do, so don't be shy about seeking the space.
- The local anesthetic choices are bupivacaine and ropivacaine. The adjunctive drugs such as clonidine, narcotics, and so forth, are for use only if the patient is going to a monitored bed. Dexmedetomidine is not currently in use as an adjunct to caudal epidural.
- Dosing depends on agent, weight, and level of block desired.
- Maintain high vigilance for dural puncture and spinal or total spinal. Remember that with total spinal, children may become unresponsive and apneic but may not manifest overt hemodynamic signs.
- Maintain the closest observation of a continuous EKG tracing to rule out intravascular injection. Peaked T-waves and widening of the QRS complex are both sensitive indicators of intravascular or intraosseous injection.

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# Avoiding the One-Hour Wake Up or How to Save the Sanity of the Parents and Your Own Reputation at the Same Time

Rachel Elisabeth Waldinger, MD MPH and Sarah Oswald, MD

The process of emerging a patient from anesthesia is both an art and a science. Many experienced anesthesia providers consider it the stage of general anesthesia that requires the most finesse from the practitioner. And if you think about the aviation industry (again), this makes sense–landing on an aircraft carrier is generally considered more perilous than launching. Remember also that there is almost certainly a very anxious set of parents waiting out there and each minute between the time they speak to the surgeon after the operative procedure and the time they see their child can seem like an hour. You never want to try to inappropriately rush an emergence but a smooth emergence and extubation that goes according to plan is a critical part of "good anesthesia."

Many external and patient-specific factors affect the time to, and ease of, emergence. However, there are some simple but reliable practices that can make emergence faster for pediatric patients. These principles improve patient care and decrease turnover times both in the operating rooms and through the postanesthesia recovery unit (PACU). Faster turnovers have implications for busy practices and on the total cost of health care.

The practices described here represent both evidence-based suggestions as well as commonly accepted practices based on experience.

## Choice of Anesthetic

- Inhaled Anesthetics
  - Of the commonly used inhaled anesthetics in the United States, there is significant evidence that emergence for children from desflurane anesthesia is fastest, and emergence for children from both desflurane and sevoflurane anesthesia is faster than from isoflurane anesthesia. There are other reasons one might choose to use a particular type of anesthesia, including patient-specific factors such as airway

hypersensitivity and system factors such as cost.

- Nitrous oxide
  - Given the low blood solubility of nitrous oxide ($N_2O$), it has a more rapid onset and offset than the other commonly used inhaled anesthetics. Although $N_2O$ is insufficient to produce anesthesia when used as the sole agent, it contributes to a faster wakeup when used in combination with volatile agents.

- Choice of Airway Management
  - For pediatric patients requiring general anesthesia, there are many reasons to choose a laryngeal mask airway (LMA) for airway management. Use of an LMA may lead to faster emergence because the patient does not require muscle relaxation and can be kept spontaneously breathing throughout the case, allowing for more precise titration of anesthetics and pain medications. Although there is a paucity of direct evidence demonstrating that LMA use results in faster emergence, there is some evidence that use of an LMA results in faster recovery from anesthesia. Also, use of an LMA can reduce the incidence of postoperative sore throat and vomiting, potentially leading to a faster discharge from the PACU.

- Pain Control Regimen
  - Patients who are given an excess of opioid pain medications intraoperatively may demonstrate longer emergence times due to sedation and/or respiratory depression. By using a multimodal pain regimen including acetaminophen, nonsteroidal anti-inflammatory drugs (NSAIDs), such as ketorolac, α-2-agonists, local anesthesia, and regional anesthesia (discussed in detail below) in combination with opioid pain medication, the sedative effects of opioids can be minimized. Opioids should be used sparingly, especially in children with obstructive sleep apnea (OSA), given their increased sensitivity to respiratory depression. Also, shorter-acting opioids are preferable to longer-acting ones in children with OSA and when a faster emergence is desired.
  - Regional and local anesthetics are safe and effective ways to minimize anesthetic depth and provide acute and long-acting pain control. By allowing a lighter plane of anesthesia due to the absence of surgical pain, effective regional anesthesia promotes a more comfortable emergence and faster wakeup times.

- Premedication
  - There is significant variation in clinical practice regarding the use of sedating medications prior to induction of anesthesia in children. Although there are pros and cons in the use of premedication there is some evidence that certain medications, especially oral midazolam, can delay emergence times after short procedures. Oral premedications often demonstrate peak activity as the time short procedures, less

than 2 hours, are ending. Therefore, in appropriate situations distraction techniques can be used in lieu of premedication to allow for faster emergences.
- Another practice used by some anesthesiologists is placement of an orogastric tube after induction and intubation to remove the remaining oral premedication from the patient's stomach. In theory, this decreases the absorption of the oral premedication and may hasten emergence.

- Communication on Expected Duration of Surgery
  - Communication with all members of the team, including patients and their families, nurses, technicians, anesthesia providers, and surgeons always results in better patient care. Because inhaled and intravenous anesthetics, opioid and nonopioid pain medications all require time to take effect and to be eliminated, it is important to have accurate estimates of when surgery will end. Therefore, good communication with surgeons, including a 10- to 20-minute notice prior to the end of surgery, allows for more precise timing of emergence.

- Bispectral Index (BIS)
  - Use of BIS in adults has been shown to shorten wakeup times and the times to recovery of verbal responses and orientation when compared to standard clinical practice alone. In pediatric patients, BIS has been shown to correlate well with depth of anesthesia for inhalational and total intravenous anesthetics. Therefore, BIS can be used as a tool to maintain an adequate, but not too deep, plane of anesthesia leading to faster emergence.

- Temperature Monitoring
  - It is well known that hypothermia slows emergence from general anesthesia. Using a temperature probe and warming devices such as warm blankets, increased room temperature, forced air warming blankets, and fluid warmers in order to preserve a patient's temperature can improve metabolism of drugs and result in a more effective wakeup.

- Muscle Relaxation
  - Avoidance of neuromuscular blockers or limiting the use of muscle relaxation to intubation may allow faster recovery of respiratory muscle function. This can accelerate readiness for extubation after surgical conclusion.

- Lidocaine Prior to Intubation
  - Lidocaine can be used to decrease airway reflexes, especially those stimulated by the presence of an endotracheal tube (ETT). Lidocaine can be given systemically or topically. For short cases, less than 2 hours, applying intratracheal lidocaine prior to intubation can result in less coughing and bucking prior to extubation, and less

coughing or airway irritation after extubation. This decrease in airway sensitivity may allow for earlier titration of the general anesthetic while the ETT is in place, potentially leading to faster emergence.

## TAKE HOME POINTS

A faster wakeup can never be guaranteed, but keeping in mind these simple techniques usually can provide a more efficient wakeup. These techniques help limit factors such as muscle weakness, respiratory depression, residual general anesthetics, and airway sensitivity while enhancing pain control and the ability to titrate medications as early as possible.

In order to achieve a faster emergence for pediatric patients keep in mind these guiding principles:

- Use the most shallow plane of anesthesia allowable by using a multimodal approach to the anesthetic and pain management.
- Carefully choose an airway management plan, including topical anesthesia, if appropriate.
- Cultivate and maintain good communication with the entire OR team regarding surgical and anesthetic plans.

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# When Not to Extubate Deep! And if the Patient Is Already Coughing or Swallowing, It's Too Late Anyway

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Extubation of a patient requires the anesthesia provider to consider both the patient's medical history and the airway examination. To avoid reversible or catastrophic complications that could lead to morbidity and mortality, extubation always should be performed only after careful assessment and at the appropriate clinical time.

This chapter focuses on contraindications to "deep extubation." We will define "awake" versus "deep" tracheal extubation and describe the advantages and disadvantages of deep extubation. Special attention will be given to extubation of an anesthetized child. Additionally, we will discuss complications associated with this technique and identify situations where deep extubation is inappropriate.

Extubation of a pediatric patient can be safely undertaken at two different points in the clinical course:

### Awake

When the anesthetic agent has worn off and the patient shows signs of wakefulness such as grimacing, frowning, chewing on the endotracheal tube (ETT) or swallowing, and has purposeful movement and/or spontaneous eye opening, then awake extubation is appropriate. This procedure should be carried out when the patient has passed stage 2 of emergence, as evidenced by the absence of irregular breathing patterns or dilated and divergent pupils.

### Deep

When the patient is breathing spontaneously, has sufficient depth of anesthesia, and does not respond to stimulation, such as laryngeal suctioning or gentle movement of the ETT, then deep extubation is appropriate.

Both approaches to extubation may be associated with significant complications, such as aspiration, laryngospasm, and postobstructive pulmonary edema. Only

experienced anesthesiologists and anesthetists should determine which approach, that is, deep or awake extubation, is appropriate.

## Advantages

There are several advantages to deep extubation. When extubating during a deep plane of anesthesia, the ETT is removed before the return of airway reactivity. This may provide a smoother emergence with less coughing and straining. In some clinical scenarios, specifically after oropharyngeal surgery, deep extubation may decrease the risk of trauma to the patient's airway while minimizing the risk of wound dehiscence and bleeding. Particularly in neurosurgery or ophthalmic surgery, smooth emergence is a goal, and deep extubation can be a maneuver that avoids increases in intracranial or ocular pressure secondary to coughing or straining. Additionally, deep extubation might lower the likelihood of laryngospasm or bronchospasm, especially in patients with reactive airway disease. However, don't make the mistake of planning a deep extubation to try to keep a patient with a recent upper respiratory tract infection (URI) on the surgical schedule. Regarding recent URIs, the depth of anesthesia at which the laryngeal mask airways (LMAs) or ETT are removed appears to have no effect on the incidence of adverse respiratory events. Children with URIs within the past 6 weeks have an overall increased risk of breath holding, secretions, and coughing, independent of the method used for extubation.

## Disadvantages

In a child whose respiratory reflexes have not fully returned yet, deep extubation results in an unprotected airway, and it increases the risk of pulmonary aspiration. Respiratory depression, secondary to residual anesthesia, can cause hypoxia and hypercarbia and consequently increases intracranial and pulmonary arterial pressure which needs to be avoided in neurosurgical patients and certain cardiovascular pathologies, such as pulmonary hypertension. The recovery room staff should be prepared to manage the patient as stage 2 of emergence will be delayed; furthermore, laryngospasm or airway obstruction is not uncommon in children following deep extubation, so an anesthesia provider trained in managing a pediatric patient's airway needs to be immediately available.

## How to Successfully Perform a Deep Extubation

- To ensure **adequate anesthesia depth** and to avoid extubation during stage 2 of emergence, there are several considerations to keep in mind. When volatile agents have been used to maintain anesthesia, an MAC of 1.5–2 is required prior to

extubation. For successful deep extubation, the necessary MAC can be reduced with concomitant use of sedatives, opioids or vocal cord topicalization with lidocaine. Deep extubation has been safely performed while administering commonly used volatile agents such as sevoflurane, isoflurane and desflurane. However, desflurane might lead to a slightly higher complication rate of coughing, breath holding, and excessive secretions. Airway irritants, such as mucus and blood, should be removed prior to extubation and thorough suctioning of the oropharynx should not elicit any response.

- To ensure a **spontaneously breathing patient**, neuromuscular blocking agents should be reversed, with a goal TOF of greater than 0.9, and a target negative inspiratory pressure of greater than 30 $cmH_2O$. Respiratory rate and tidal volume should be age appropriate and adequate.
- Signs of **upper airway obstruction**, such as mild stridor, paradoxical chest and abdominal movement, are common after deep extubation. Upper airway obstruction often responds to mild support maneuvers such as placing the patient in lateral decubitus position to prevent blood and secretions from tracking down the airway and maintaining airway patency with a jaw thrust and/or chin lift. Supplemental oxygen administration is recommended in this situation.
- Regarding **airway devices**, studies suggest that the removal of LMAs in a deeply anesthetized child may provide a lower risk of respiratory complications upon emergence. This advantage is less evident when removing ETTs. Controversy still exists regarding whether or not deep extubation of ETTs increases or decreases the risk of adverse respiratory events.
- As noted in the Disadvantages section, when a patient emerges in the recovery room, it is imperative that the **recovery room staff** be available to ensure airway patency and be trained in supporting the airway, should the need arise.

Not every child is an appropriate candidate for this procedure. It is crucial to recognize contraindications to deep extubation in order to avoid serious complications and potentially adverse outcomes.

## Contraindications to Deep Extubation

- Situations with increased **risk of aspiration** upon emergence, such as pyloric stenosis, hiatal hernia, severe gastroesophageal reflux disease, full stomach, and emergency surgery preclude deep extubation. In these scenarios, awake extubation is strongly recommended.
- **Difficult airways,** such as the inability to mask ventilate a patient or difficulty intubating a patient, are contraindications to deep extubation. Under these circumstances, removal of the ETT in an awake patient with intact airway reflexes is

recommended.

- After **tonsillectomies and adenoidectomies**, deep extubation has been used as a way to prevent coughing and bucking, which may lead to bleeding, but this practice is still controversial. To ensure adequate airway reflexes, the literature suggests that the patient should be fully awake for extubation.
- **Morbid obesity** is a common risk factor for **obstructive sleep apnea** in children, and is associated with a higher risk of upper airway obstruction. These children should be extubated when fully awake to ensure full airway muscle control.
- Both inadequate **recovery room monitoring** of an anesthetized child and the inability to manage the emergence of a child due to a lack of immediately available, trained providers could be reasons to avoid deep extubation in certain medical centers.

## TAKE HOME POINTS

- Deep extubation is an advanced technique which should only be performed by experienced pediatric anesthesia providers.
- There is a narrow window in the clinical course for deep extubation. If you miss it, then don't extubate until the patient meets the criteria for awake extubation.
- Deep extubation is reserved for patients without increased aspiration risk and whose airway management posed no significant difficulty.
- Deep extubation decreases the risk of postoperative straining and bucking, but these advantages can be offset by the potential increases in the incidence of upper airway obstruction in certain clinical scenarios.
- Deep extubation does not lessen the risk of postemergence and postextubation airway difficulties in children with recent URIs.

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# Emergence Delirium—Don't Overcall It, Don't Undercall It, and Don't Let It Happen

Chelsea Willie, MD and Kimberly Blasius, MD

Emergence Delirium (ED), also frequently called emergence agitation, is a **diagnosis of exclusion** defined as a disoriented patient who is incognizant of his or her surroundings and previously familiar individuals/objects, and who is generally inconsolable and uncooperative. While usually of relatively short duration, generally less than 30 minutes, ED can lead to many undesirable consequences. These include an inability to monitor the patient, disconnected or lost intravenous lines, physical trauma to the patient, and physical trauma to the caregivers. Lastly, additional time and/or resources may be required in the recovery room.

## Diagnosis

The true incidence of ED has not been precisely defined, instead being estimated to occur during **2% to 80%** of anesthetics. However, we feel that if you are seeing ED in a high percentage of your cases, you need to be taking a hard look at everything in your practice, not just this chapter.

Historically, ED was frequently overcalled. For example, hypoxia, inadequate analgesia, hypoglycemia, hypercarbia, nausea, and bladder distention are all factors to consider prior to settling on ED as the diagnosis for a pediatric patient's postoperative disorientation and agitation.

Conversely, ED is still sometimes undercalled. The factors that are most sensitive and specific for ED include inconsolability and staring with averted eyes rather than a direct gaze. Behavior ranges from incoherence, inconsolability, thrashing, and agitation to paranoia or hallucinations.

What is known is that ED incidence is higher in children from age 2 to 4 years; males; sevoflurane or desflurane anesthesia; ear, nose, and throat surgery; and in children with preoperative anxiety. Previously, there wasn't a reliable and valid instrument for measuring ED in children. Many scales confused behaviors such as crying, agitation, and lack of cooperation with delirium, failing to recognize that these

behaviors could be consistent with other emergence responses such as pain or fear.

The Pediatric Anesthesia Emergence Delirium (PAED) Scale was developed in 2004. This scale uses the framework of a delirium-like state based as defined by the Diagnostic and Statistical Manual of Mental Disorders. The PAED focuses on consciousness and cognition, as opposed to those behaviors associated with pain, such as crying and agitation. The PAED uses a 5-point Likert scale to score behaviors that include eye contact, purposeful actions, awareness of surroundings, restlessness, and inconsolability.

In 2014, Stamper et al. directly compared the PAED to the commonly used Level of Consciousness-Richmond Agitation and Sedation Scale (LOC-RASS) to assess delirium. The study revealed that the incidence of delirium was 11.5% with the PAED scale versus 7.5% with the LOC-RASS, suggesting that the PAED was a more sensitive and effective tool to identify pediatric emergence delirium.

## Causes

Although various etiologies have been postulated to cause ED, a definitive causality has yet to be identified. Volatile anesthetics (halothane, isoflurane, sevoflurane, and desflurane) are associated with an ED incidence that has been reported to be as high as 50%. Sevoflurane and desflurane have been extensively studied and have a higher incidence of ED as compared to halothane and isoflurane. Their low blood gas solubility quotient with rapid emergence has been theorized to lead to more ED, even though the speed of emergence has not been found to be a cause of ED. The use of droperidol, atropine, and scopolamine are associated with ED, whereas maintenance anesthesia with propofol is associated with a lower incidence of ED.

Pain has been implicated as a cause of ED, which makes sense intuitively, and is also consistent with the successful use of analgesics to both treat and prevent ED. As tidy as this theory is, however, it provides only a partial clue to the etiology of ED since the condition also occurs after anesthetics for nonpainful procedures, such as MRI.

## MRI

An additional factor in the higher incidence of emergence delirium in the pediatric population may be due to psychological immaturity and lack of ability to cope with anxiety. This is likely secondary to the chemical composition and brain network connectivity of young children.

## Treatment

At present, there are no drugs that have an FDA-approved indication for ED. While

prophylaxis is preferable to avoid the harmful effects of ED, many treatment options exist among our most commonly used drugs. These drugs can frequently be used for both treatment and prevention; for example, fentanyl, midazolam, clonidine, dexmedetomidine, and propofol.

**Fentanyl** has been frequently used to treat postoperative ED after both noxious procedures and nonpainful procedures, which suggest a more complex etiology to ED than somatic pain. Fentanyl also has the advantage of usually being fairly readily at hand. The appropriate dose is 1 to 2 μg/kg.

**Midazolam** has been found to relieve postoperative ED, but can lead to prolonged recovery time, so is not as commonly used for ED treatment. The appropriate dose is 0.025 mg/kg.

**Propofol** is gathering popularity as treatment for ED as it is also readily available and exhibits the benefits of relatively rapid onset and offset. The appropriate dose is 0.5 to 1 mg/kg.

**Clonidine**, besides being reported to be efficacious for prevention, has been used anecdotally for treatment, besides being reported to be efficacious for prevention.

**Dexmedetomidine** is becoming a popular treatment option for ED, although it has not been formally studied for this indication. The benefit of treatment with a drug such as dexmedetomidine is the additional effect of analgesia and prevention of PONV, although it can lead to delay in PACU discharge.

## Prevention

The best way to treat ED is to **prevent it from occurring** and this should be part of every anesthetic plan. Many prevention strategies for ED center around attenuating preoperative anxiety.

Drugs utilized to **prevent ED** have included fentanyl, propofol, ketamine, clonidine, dexmedetomidine, midazolam, and dexamethasone. Both the specific drug and the timing of its administration are important.

The efficacy of fentanyl as a prophylactic against ED has been demonstrated in several studies. Fentanyl, given in a small dose of 1 μg/kg IV **10 minutes before anesthetic discontinuation of sevoflurane**, lowered ED incidence compared to placebo (12% vs. 56%) in pediatric patients aged 18 months to 10 years old undergoing outpatient MRI. Another study randomized a group of 110 developmentally delayed ASA 1 to 2 patients undergoing sevoflurane anesthesia for dental restoration to 1 to 1.5 μg/kg fentanyl or saline at induction of anesthesia. The incidence of ED was lowered, without increasing nausea/vomiting or time to discharge.

**Midazolam** can be used to decrease the incidence of ED, but the timing of administration is important. Midazolam as a premedication does not consistently reduce

ED incidence, but if given "at the end of surgery" (i.e., when the dressing is applied) will decrease the incidence of ED. Several doses have been studied—no prolongation of emergence was found with a 0.03 mg/kg dose of midazolam, while a dose of 0.05 mg/kg was found to delay emergence by about 4 minutes.

**Propofol** at the end of surgery or as a continuous infusion can be used to prevent ED (the short half-life of propofol likely renders ineffective against ED when given only for induction). Also, consider a propofol/remifentanil anesthetic, instead of sevoflurane, for nonpainful procedures such as MRI.

Ketamine has also been shown to work for ED prophylaxis, although the mechanism is not fully understood, given the manifold sedative, amnestic, and analgesic effects of ketamine and it can be associated with prolonged recovery times and nausea and vomiting. However, in one study, a cohort of children, aged 4 to 7 years, underwent dental repair under sevoflurane anesthesia. The patients were premedicated with midazolam and acetaminophen and were given ketamine (0.25 mg/kg IV) or saline 10 minutes before the end of the surgery. The incidence of ED was decreased in the ketamine group with no significant adverse effects.

Intraoperative use of the α-2 adrenergic agonists **clonidine** and **dexmedetomidine** has also been described to provide significant ED prophylaxis in a number of studies. The clonidine studies included males aged 2 to 7 years undergoing sevoflurane anesthesia for circumcision and ASA 1 to 2 children undergoing day surgery. The clonidine dose was **2 μg/kg IV given prior to induction.** No increase in time to emergence was seen, compared to children who received a saline placebo.

Dexmedetomidine is eight times more specific for the α-2 receptor than clonidine, making it more attractive than clonidine for its sedative and analgesic properties.

In one study comparing **dexmedetomidine** to propofol for ED prophylaxis, a dose of dexmedetomidine (0.3 mg/kg IV) was superior to propofol (1 mg/kg IV) when each was given 5 minutes before the end of surgery.

A continuous infusion of dexmedetomidine is also effective in ED prevention. Direct comparison between a dexmedetomidine infusion (1 μg/kg/hr) and ketamine infusion (1 mg/kg/hr) in 84 children having strabismus surgery revealed comparable significant decreases in ED when compared to placebo, with dexmedetomidine being superior in prevention of postoperative vomiting. Dexmedetomidine may include prolonged recovery times in the postoperative care unit, but the benefits of analgesia, postoperative vomiting prevention, and decreased ED incidence makes it an attractive choice for ED prophylaxis.

Lastly, **dexamethasone** can be used for ED prevention. In one study, dexamethasone (0.2 mg/kg IV) or acetaminophen/codeine syrup (0.25 mL/kg PO) or placebo were compared as premedication for emergence agitation and pain. It was found that in the

dexamethasone and acetaminophen/codeine group agitation was less than that in the placebo group with no difference between the intervention groups. There was no significant effect on postoperative pain control compared to placebo. The researchers proposed that the anti-inflammatory effect of these medications may have an effect on postoperative agitation.

Remember that with time, ED usually resolves; therefore, a commonly employed strategy is gentle restraint of the patient until the ED passes. The decision to wait rather than treat will depend on the severity of the ED, the availability of extra PACU staff to help care for the child, and the risk of injury or morbidity secondary to loss of invasive catheters and/or surgical drains.

## TAKE HOME POINTS

- It is important to remember that ED is a **diagnosis of exclusion**. Failing to rule out other causes could have serious sequelae.
- ED is more properly thought of as a form of delirium, not agitation. Factors most sensitive and specific for ED include inconsolability and staring with averted eyes rather than a direct gaze.
- The Pediatric Anesthesia Emergence Delirium (PAED) Scale is the most reliable measurement for assessment of ED.
- Every pediatric anesthesia plan should address ED prophylaxis and treatment, if it is needed in spite of careful planning.
- ED can be severe and children can hurt themselves and the care givers. One of the worst cases the editors ever saw was a child who was literally screaming and throwing himself around. Remember, verbal redirection will not work in this type of situation. Get the anesthesia toolbox open as quickly as possible. And do not make the mistake of thinking the parents will be able to "settle the patient down." They won't. The parents should definitely not be reunited with the child until the ED has resolved.
- Reliable treatments for ED are fentanyl (1 to 2 μg/kg) and propofol (0.5 to 1 mg/kg). These are the best first-line treatments because they are so familiar to us and usually readily at hand. Also, at these doses the drugs will not cause much in the way of prolonged emergence.
- Prevention of ED is best. Fentanyl (1 μg/kg) given either at the start of the case or 10 minutes before the discontinuation of sevoflurane is helpful, even if the procedure is not painful. Other possibilities for prophylaxis of ED include midazolam (0.03 mg/kg IV) given at the end of surgery, ketamine (0.25 mg/kg IV), clonidine (2 μg/kg IV) given before induction, and dexmedetomidine (0.3 mg/kg IV) 5 minutes before the end of surgery. Propofol infusions or a propofol bolus at the end of a case will

also decrease the incidence of ED.

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# Too Much, Too Little, Just Right: Avoiding Opioid Withdrawal in Pediatric Patients on Chronic Opioids

Jeffrey L. Koh, MD MBA and Elizabeth Pedigo, MD

As we have gained a better understanding of pain in children in recent years, opioid administration for both acute and chronic pain has increased significantly. With this, iatrogenic opioid dependence and the potential for withdrawal have also increased. Children in intensive care settings are particularly at risk, as they may require prolonged exposure to opioids and sedatives to manage pain and distress associated with a critical illness. As experts in the use of opioids for pain relief, it is important that anesthesiologists also understand the basic principles of managing iatrogenic opioid dependence.

**There is considerable interpatient variation in how fast opioids can be weaned and when withdrawal symptoms appear.** In most cases, patients who have been on opioid less than 7 days can have their opioid medication stopped without signs of withdrawal. Patients on opioid for greater than 14 days should be gradually weaned from their opioid medication to avoid symptoms of opioid withdrawal. Patients on higher doses of opioid or particularly long exposure usually need a weaning plan that covers several weeks. Before starting to wean opioids, it is extremely important to understand the patient's current pain stimulus. If they have ongoing pain or will be going to surgery soon, it may not be the best time to start an opioid wean.

## Signs and Symptoms of Withdrawal

It has been shown both in the lab and in clinical trials that patients can develop opioid tolerance in as little as 5 days, and therefore are at risk for developing withdrawal symptoms with abrupt cessation of opioids even after a short course of treatment. Symptoms of withdrawal are similar to those seen in adults, but may be less clear-cut in younger children (Table 209.1).

While these signs and symptoms may be obvious, they can be confused with symptoms of illness or behavioral issues. The appearance of these signs and symptoms

in the context of a recent decrease or discontinuation of opioids should at least raise the possibility of withdrawal symptoms. In addition, changes in a patient's ability to absorb oral opioid medication can also result in the appearance of withdrawal symptoms.

## Basics of the Opioid Wean

There is no perfect plan for successfully weaning a patient off opioids. General recommendations have been published, but a key factor should be monitoring the individual response of a patient and modifying the weaning protocol as needed. Some basic rules for patients who have had prolonged opioid exposure:

- Calculate the average 24-hour opioid requirement for the patient over the last several days. Don't forget to include as needed (PRN) opioid administration.
- Convert a reasonable portion of the 24-hour requirement (50% to 75%) to methadone (or other long-acting opioid) and administer every 6 to 8 hours.
- Oral administration is ideal, but weaning can be started using IV administration.
- Make the remainder of the opioid requirement available as PRN short-acting opioid. This can be used for either breakthrough pain, pain related to procedures, or signs of withdrawal.
- Reassess in 24 hours to determine PRN requirements and consider increasing baseline opioid dosing if the patient required more than 4 PRN doses in 24 hours.
- Once stable, initiate wean by decreasing total daily dose by 10% to 20% every 24 to 48 hours. This can be done by either decreasing the dose size, and/or decreasing the frequency of dosing.
- If signs of withdrawal occur, provide additional opioid and consider increasing the methadone dose 10%. It is usually a good idea to pause the opioid wean for a few days until symptoms have subsided.
- Once opioids are discontinued completely, parents and caregivers should continue to watch for signs of withdrawal for several days.
- If the patient requires surgery or other procedures that may increase their baseline pain, hold the weaning plan at current dosing and ensure they have adequate PRN medication to treat postoperative pain. The wean can be restarted once their postoperative pain subsides.

**Table 209.1 ■ Opioid Withdrawal Symptoms**

| Organ System | Sign/Symptom |
|---|---|
| CNS | |
| | Anxiety |

| | |
|---|---|
| | Agitation |
| | Grimacing |
| | Sleep disturbance |
| | Muscle tension |
| GI | |
| | Diarrhea |
| | Vomiting |
| | Increased gastric residuals |
| Autonomic | |
| | Tachypnea |
| | Sweating |
| | Fever |
| | Hypertension |

Opioid conversion suggestions are shown in Table 209.2. It is important to remember that the conversion to methadone from other opioid is not an exact calculation; therefore it is prudent to only give a proportion of the patient's 24-hour requirement as methadone (or another long-acting opioid) initially to avoid adverse effects such as somnolence and respiratory depression. In addition, converting from parenteral to oral dosing brings additional variability that should be taken in to account. Daily reevaluation of their response to the conversion and PRN requirement will allow titration of the methadone dose for individual patients.

Adjunctive medications such as clonidine, gabapentin, and dexmedetomidine have been used to decrease withdrawal symptoms, but there is very little information in the literature to guide their use for this purpose. Behavioral strategies may also be helpful in managing sleep hygiene, anxiety, and pain-related symptoms.

## Benzodiazepine Dependence

Finally, it is not uncommon for hospitalized patients who have required long-term opioids to also receive benzodiazepine administration during this same period. Abrupt cessation of benzodiazepines can result in withdrawal symptoms similar to opioid withdrawal in terms of general somatic complaints. Remember also that benzodiazepine withdrawal can result in life-threatening neurologic instability as well. Although there are no clear guidelines for this situation, it would seem prudent to consider a weaning

plan for the benzodiazepines as well. Some have used conversion to lorazepam to aid in this process. A common approach is to wean one medication (benzodiazepine or opioid) at a time in order to prevent confusion as to which may be causing withdrawal symptoms and to minimize and mitigate the withdrawal syndromes.

**Table 209.2 ■ Opioid Conversion**

| Drug | IV Equianalgesic Dosing (mg) |
|---|---|
| Morphine | 10 |
| Fentanyl | 0.1 |
| Hydromorphone | 1.5 |
| Methadone | 10 |

Adapted from Anand KJ, Wilson DF, Berger J, et al; Eunice Kennedy Shriver National Institute of Child Health and Human Development Collaborative Pediatric Critical Care Research Network. Tolerance and withdrawal from prolonged opioid use in critically ill children. Pediatrics. 2010;125(5):e1208–e1225.

## TAKE HOME POINTS

- Opioid withdrawal symptoms is most commonly seen when patients have had at least 2 weeks of exposure, but can be seen with as little as 5 days exposure.
- Signs and symptoms of withdrawal can be confused with other etiologies, but should be considered in the context of prolonged opioid use and changes in opioid dosing or absorption.
- Weaning plans should be individualized but most patients can be weaned safely using longer-acting opioids such as methadone. Short-acting opioids should also be available for breakthrough symptoms or painful procedures.
- Weaning should be held and additional short action medication available when surgery is required during the weaning period.
- Benzodiazepine withdrawal can cause similar and/or life-threatening symptoms and requires a weaning plan coordinated with opioid weans.

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# Careful and Conservative Clinical Judgment Is Required Before Discharging a Pediatric Patient to Home

Peggy P. McNaull, MD and Eva J. Waller, MD

Don't let the surgeon discharge every pediatric patient home!

Idiopathic apnea occurs in up to 55% of infants born prior to 37 weeks of gestation and in up to 2% to 3% of full-term infants. All infants, especially those born prematurely, are at risk for postoperative apnea. It is crucial to identify those infants at increased risk for postoperative apnea in order to provide extended monitoring and intervention when necessary.

Apnea is defined as an unexplained pause in breathing lasting 15 to 20 seconds or one lasting less than 15 seconds when associated with bradycardia (heart rate <80), cyanosis, pallor, or marked hypotonia. There are three identifiable types of apnea. Central apnea is characterized by a lack of respiratory effort. Obstructive apnea exists when respiratory effort is present without airflow. Mixed apnea is a combination of both central and obstructive mechanisms.

**The most common pattern of apnea in infants has a mixed etiology, with central apnea playing the predominant role.** Infants, particularly those born prematurely, have an immature central nervous system that manifests as a decreased response to carbon dioxide and a paradoxical response to hypoxia/hypoxemia, leading to apnea rather than hyperventilation. Other contributing factors to neonatal apnea include immature intercostal and diaphragmatic musculature, an unstable pliable rib cage, an easily obstructed upper airway, and a lower airway prone to collapse. The long-term consequences of apnea are largely undefined. However, it is reasonable to conclude that hypoxemia associated with repeated apnea increases the likelihood of central nervous system damage.

Anesthesia accentuates a neonate's propensity for apneic events. **The risk of apnea is greatest during the first 12 hours after surgery but still remains for up to 72**

**hours postop.** Both inhalational and intravenous anesthetics alter respiratory function. Inhaled anesthetics compromise the infant's immature central nervous system. They have been shown to reduce the central response to respiratory stimulants, including hypercarbia and hypoxia, and to enhance the response to inhibitory afferents. Furthermore, inhaled anesthetics relax pharyngeal musculature, promoting upper airway obstruction in the neonate who is already prone to obstructive apnea. Intravenous anesthetics, including opioids, also depress the central nervous system respiratory centers.

One option for preventing or reducing postoperative apnea in preterm infants is perioperative administration of caffeine (5 to 10 mg/kg). Caffeine, a methylxanthine, is thought to stimulate breathing by promoting central nervous system excitation, increasing intercostal and diaphragmatic muscle performance, and augmenting chemoreceptor responsiveness to hypercarbia and hypoxemia. Two small studies have demonstrated the usefulness of caffeine to prevent postoperative apnea in infants. Nonetheless, absolute indications for perioperative administration of caffeine remain to be determined by larger studies intended to identify those infants who would most benefit from the drug.

Investigators have attempted to determine if regional anesthesia reduces the incidence of postoperative apnea in infants. A 2015 meta-analysis included five small studies comparing spinal anesthesia and general anesthesia with respect to the incidence of postoperative apnea following inguinal hernia repair. It failed to demonstrate a statistically significant difference in the percentage of infants with postoperative apnea or postoperative oxygen desaturation based upon anesthetic technique. However, when infants given pre- or intraoperative sedatives were excluded, the meta-analysis suggested a lower incidence of postoperative apnea in the spinal anesthetic group of up to 47%.

A recent prospective randomized trial compared the incidence of apnea in 722 infants undergoing inguinal hernia repair with regional anesthesia versus combined general and regional anesthesia. No significant difference in the overall incidence of apnea was found. However, the incidence of early apnea (defined as occurring within 30 minutes postop) was significantly lower in infants receiving regional anesthesia alone. In addition, the degree of oxygen desaturation and level of intervention for apnea were reduced, implying that apnea after regional alone was less severe.

Postoperative apnea is reported to have occurred in infants up to 55 weeks of postconceptual age (postconceptual age = gestational age + age after birth) following extensive surgical procedures. Identifying at-risk infants and determining their need for postoperative monitoring following anesthesia is a great challenge. Many investigators have attempted to identify those infants at greatest risk. In a meta-analysis of eight

published reports involving 255 prematurely born infants following inguinal hernia repair, the data revealed that there is a strong inverse relationship between apnea and gestational age as well as postconceptual age. The authors estimate that the risk of apnea is not less than 1% until postconceptual age is 54 weeks and gestational age is 35 weeks. The meta-analysis found continuing apnea at home and anemia (hematocrit <30), especially for infants greater than 43 weeks of postconceptual age, are additional risk factors for postoperative apnea. Finally, the authors determined the majority of apneic spells resolve without intervention; however, they were unable to identify predictors of the likelihood of self-recovery from an apnea spell.

Based upon reported investigations, general recommendations and guidelines employed at our institution include:

) An infant's need for extended postoperative monitoring is evaluated on a case-by-case basis, considering the patient's gestational and postconceptual age, ongoing apneic events, hematocrit, other comorbidities, and type of surgery.

) Elective surgery for term infants is delayed until infants are greater than 44 weeks of postconceptual age.

) Premature infants less than 50 weeks of postconceptual age are admitted and monitored for at least 18 hours postoperatively. Infants between 50 to 60 weeks postconceptual age are monitored in our PACU for a minimum of 2 hours prior to discharge home.

) It must be noted that guidelines may vary from one institution to another; it is important to follow the guidelines in your practice location and assess additional risk factors for apnea. When in doubt, be more conservative than the guidelines and admit the patient for observation and apnea monitoring. If you have to, admit freely that you are purposely making a conservation management decision because the consequences of being wrong are so high. Never discharge a patient if the case has not met your institution's guidelines.

## TAKE HOME POINTS

- Don't wonder if the infant you are taking care of will have postoperative apneic episodes; instead, assume they will. The risk is inversely proportional to age and postconceptual age.
- Apnea in infants can be either central or obstructive—a mixed etiology is the most common.
- The immature pediatric nervous system reacts paradoxically to increased blood

carbon dioxide and hypoxemia, leading to apnea instead of hyperventilation. This maladaptive physiology is exaggerated in premature infants.

- Studies have not established that regional anesthesia will prevent postoperative apneic episodes. However, there is evidence that regional anesthesia may be associated with fewer apneic events and that they may occur earlier in the postoperative period.
- Discharge decisions for infants should involve your most carefully considered clinical and conservative judgment. Don't break your hospital's policy and don't let anybody substitute their judgment for yours.

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# Chronic Pediatric Pain: There's Always More Than Enough Pain for Everybody Involved and It's Not About the Blocks!

Elizabeth Pedigo, MD, Jorge Alberto Pineda Jr, MD, and Jeffrey L. Koh, MD MBA

The pediatric patient who suffers from and deals with chronic pain is one of the most deserving and challenging patients that you will ever see in your practice of anesthesiology. You may see a pediatric chronic pain patient in the preoperative or postoperative period, in the operating room, in the pain clinic, or you may even get a curbside request for information and help from another service as you are walking around the hospital at night.

Chronic pain has been shown to occur in a significant number of children, at least for some portion of their lives. Chronic pain in the pediatric population manifests with a distressingly wide array of symptoms, including headaches, abdominal pain, neuropathic pain, bone pain, and complex regional pain syndrome (CRPS).

Sadly, chronic pediatric pain can also be related to an underlying medical condition such as cancer or cerebral palsy. Occasionally, it can appear to have "no reason" at all.

As the perioperative experts in analgesic techniques in most institutions, it is likely you will be either directly caring for these patients, or at least asked to provide consultation.

It is also incredibly important for the anesthesiologist to understand on a fundamental level that a child in pain means a parent in pain, as well. If there is ever a time to recall the "bio-psycho-social" model of medical care that you first heard about in medical school, this is it. Do your utmost to take the best possible care of these little patients and their parents. If you yourself are a parent (especially a mom!), do not be surprised to experience some level of personal distress.

These are some of the challenges you may face in the perioperative period or during a hospital stay:

- How to avoid undertreatment of postoperative pain in kids with chronic pain.
- How to avoid opioid withdrawal in patients on chronic opioid management.
- How to recognize that "this patient needs a block" is not the best first step in the

assessment and management of chronic pain patients.

## Managing Postoperative Pain in Children With Chronic Pain

"This kid is on a ton of opioids, how do I manage him postoperatively?"

Postoperative care of a child who has been taking opioids previously can be a challenge to anesthesiologists. Safely achieving adequate analgesia without causing respiratory depression can be intimidating, time consuming, and difficult to maintain. Similarly, undertreating patients with postoperative opioids can lead not only to inadequate pain management but also to opioid withdrawal symptoms. Several strategies are presented here to guide the anesthesiologist to prevent opioid withdrawal, maintain adequate pain control, and satisfy the expectations of the patient, the patient's family, as well as the rest of the health care team postoperatively.

## Preventing Opioid Withdrawal

Opioids can be used effectively in patients with chronic pain postoperatively, but there are several potential pitfalls. First, opioid withdrawal is not uncommon postoperatively as health care providers often do not recognize that routine opioid dosing for postoperative pain may be inadequate to prevent withdrawal in patients on chronic opioids. An easy way to help prevent opiate withdrawal in a patient who has been on opioids longer than 1 to 2 weeks is to simply maintain the baseline medications he or she was previously taking, and then prescribe "routine" dosing of opioids for postoperative pain on top of their baseline. This is especially important if patients are taking long-acting oral (PO) pain medications such as oxycontin, methadone, or transdermal medications. If the patient's NPO status precludes continuing their oral baseline opioid administration, then a calculation must be performed utilizing an opiate equivalency chart so that an equal analgesic dose can be administered to the patient intravenously. Please keep in mind that the bioavailability of PO medications may be altered postoperatively due to delayed gastric emptying or ileus.

## Avoiding Inadequate Postoperative Pain Management

Another potential pitfall in managing patients with chronic pain is the undertreatment of their postoperative pain. It is important to keep in mind that these patients' opioid requirements may be **three times higher** than that of opioid naïve patients. Multiple factors contribute to such a significant increase including tolerance, receptor downregulation, altered pain sensitivity, psychopathology, and disease progression. Just as important, however, is this patient population's predisposition to opioid-induced

hyperalgesia. Rotation to a different opiate, utilizing neuraxial techniques or peripheral nerve blocks, as well as nonopioid analgesics can all be vital in providing adequate pain management postoperatively. If the decision is made to perform regional anesthesia, information must be provided to the patient, family, and team regarding analgesic management and expectations for when the block wears off.

In addition to maintaining the patient's existing opioid regime, continuing any nonopioid analgesics they are taking can also be vital to providing a comfortable postoperative experience. α-Antagonists, anticonvulsants, acetaminophen, NSAIDs, and antidepressants should not be stopped in the setting of surgery unless necessary secondary to surgeon instruction. If a patient is taking only opioid medications for pain control at the time of surgery, the anesthesiologist may also consider starting a nonopioid pain adjuvant if he or she believes the pain medication requirement will be greatly escalated postoperatively. In addition to the use of acetaminophen and NSAIDs, it has been suggested that giving gabapentin preoperatively may improve postoperative pain levels, but reports in the literature are equivocal up to this point. Dexmedetomidine may have a role as well, although it is unclear if there is benefit beyond the immediate postoperative period. Finally, keep in mind that ketamine is an extremely useful adjuvant in the inpatient setting for patients with pain refractory to opioids. Ketamine, being an NMDA antagonist, is an especially useful medication for neuralgia and allodynia intraoperatively and postoperatively.

Regional analgesia, especially utilizing a continuous catheter technique, can also be quite helpful postoperatively**. It is critical to remember that the patient receiving regional analgesia will still require systemic opioids to prevent withdrawal**, and possibly for breakthrough pain. In addition, the regional technique may not be effective for managing their underlying chronic pain, further reinforcing the importance of continuing the baseline analgesic regimen when possible.

Perhaps the most vital aspect to caring for a child on chronic opioids is preparation of the patient, family, and entire team (nursing, oncology, physical therapy, psychology, etc.) preoperatively. Family expectations, postoperative analgesia planning, pain assessment tools, and coping strategies should all be discussed. If the pain management service has been involved with the patient previously, it is useful to utilize the care coordination that such a service offers. Careful discussion with the family about the child's coping skills and pain tolerance followed by a thorough history and physical examination may reveal a stoic child who is brushing off a significant level of pain, or a child with poor pain tolerance and coping skills. There may also be cultural differences that may affect a child's pain expression, such as the intensity of pain behaviors, and may also be modified by the observer's cultural norm of perception and awareness and, therefore, treatment, which may affect the overall pain experience.

In summary, postoperative pain management in patients with chronic pain can be optimized by the following general guidelines:

) Have a clear understanding of the medication a patient is taking preoperatively in order to manage their chronic pain.
) Consider utilizing regional anesthesia, or neuraxial blocks as part of your anesthetic technique.
) Consider utilizing adjunctive agents such as ketamine, dexmedetomidine, and gabapentin.
) Ensure the patient is getting adequate opioid postoperatively to prevent withdrawal, with additional analgesia to adequately treat their postoperative pain.
) Utilize the acute pain service, if available, to maximize the patient's analgesic regimen.

## Avoiding the "Block Is the Cure" Trap

The pediatricians want a block. Should I do it?

Primary care physicians, including pediatricians, do not always have experience taking care of patients with chronic pain. As experts in providing pain relief, anesthesiologists may be approached to provide assistance in the management of these complex patients. Given that much of the literature available about chronic pain refers to the adult population, anesthesiologists may be asked to perform a block that has been reported to be helpful for chronic pain in the adult population. However, clinical experience at multiple centers has shown a multidisciplinary approach to managing chronic pain in children has the best chance of long-term success. While peripheral nerve blocks can be an effective component of a multidisciplinary approach to chronic pain management, it is important for the anesthesiologist to have a basic understanding of the evaluation of pediatric patients with chronic pain to avoid falling in to the "we just need a block" trap, which is usually not in the patient's best interest.

## Pediatric Chronic Pain and Peripheral Nerve Blocks

Peripheral nerve blocks provide a means of targeting a painful area of interest for focused pain management, with the goal of lowering (or eliminating) the amount of systemic therapy needed, thus lowering the potential side effects of systemic therapy. The increased availability of high-resolution ultrasound guidance has caused an increase in interest in and use of regional anesthesia in pediatric pain management, especially in the management of postoperative pain. Indications for the use of regional anesthesia are quite varied, as are the goals of incorporating such techniques. Regional techniques can be used in the management of a wide range of chronic pain states, having

been successfully used in the management of trauma-related and nontrauma-related neuropathic pain, spasticity, where systemic therapy is failing to control a patient's pain, in the treatment of acute-on-chronic pain, as a bridge to help in controlling pain as systemic therapy is adjusted, and as part of a palliative care plan. Blocks are rarely used as the sole therapy for chronic pain and are typically part of a combined approach involving systemic medical therapy, physiotherapy, and psychological therapy.

Many of the regional techniques used for the management of adult chronic pain, can also be used in the management of pediatric patients. Differences other than the wide variation in size and maturity of the patient include issues with consent, and an age appropriate plan to perform the block safely. Deep sedation or general anesthesia is often required to perform a block in a child. Some groups describe performing blocks on children with purely psychological support, but the majority of blocks are performed with some level of sedation. The Pediatric Regional Anesthesia Network (PRAN) is a multicenter, prospective, collaborative effort for research and quality improvement that addresses this issue. In the most recent report, Polaner and colleagues give a favorable impression of the safety of modern pediatric regional anesthesia practice.

Knowing when to perform a block depends on many factors. Special considerations include the risks and benefits of the block; block placement; and in particular whether catheter placement is inadvisable in patients with abnormalities in coagulation, neutropenia, systemic infection, infection at the insertion site, or significant anatomic abnormalities at the site of insertion. Occasionally, benefits of performing the block may supersede some of the risk; for instance, the risk of giving blood products in order to allow performance of a block may be deemed appropriate to the patient in palliative care with pain uncontrolled by systemic therapy. **Risk-benefit ratios should always be kept in mind.** Addition of a regional technique to a multidisciplinary approach should advance the goal of enhancing function and quality of life.

## Evaluating a Chronic Pain Patient

Most pediatric pain programs around the country utilize a multidisciplinary approach to the evaluation and management of chronic pain in children. While many practicing anesthesiologists may not have access to such programs, they should be able to provide guidance about the initial evaluation and initial management for most common chronic pain problems. While a full description of the evaluation of pediatric chronic pain patients is beyond the scope of this chapter, the following is a summary that will hopefully prove a useful guide:

## Chronic Pain History

- Onset: specific event/trauma/strain

- Quality of pain: sharp, achy, burning
- Temporal pattern: periodic, continuous, any pain-free periods, worse at certain times of day
- Localized, multiple painful areas, radiating pain?
- Intensity of pain: average, worst
- What makes the pain worse: activity, stress, foods, light touch?
- What makes the pain better: heat, cold, specific medications?
- Does the pain affect sleep: falling asleep versus waking in the middle of the night versus both?
- Does the pain affect normal daily activities: school, social activity, family activities, work?
- How is school performance? Attending school? Home tutor? Keeping up?
- Medications: currently taking or have tried
- Previous evaluation: pain dependent—GI workup; neurologic workup, other
- Use of complementary regimen: acupuncture, herbal remedies, naturopath, massage therapy
- Previous behavioral evaluation and intervention: pain specific or more generalized?
- Previous chronic pain history?
- Family history of chronic pain problems

While the history is probably the most important part of the evaluation of a chronic pain patient, the physical examination is important to confirm the history and objectively evaluate function.

## Chronic Pain Examination

- Overall observations: Moving freely? Guarding? Engaged or "shut down"? Interaction with parents?
- All major systems should be examined, although focus of examination can be on the relevant system(s)
- Painful areas: range of motion, swelling, edema, tenderness to palpation, trigger points, guarding, focal versus more generalized pain, allodynia, color change, temperature differential, muscle wasting, abnormal sensation or strength
- General physical condition: generalized tenderness, inflexible, deconditioned, gait

## Management of Chronic Pain in Pediatric Patients

Although specific recommendations will depend on the results of the history and physical examination, there are some basic principles to the management of most chronic pain conditions that can help guide the anesthesiologist's recommendation.

- Goals of chronic pain management: In most cases, the primary goal of intervention for

a chronic pediatric pain patient should be the return to function and normal daily activity. The secondary goal is decreasing the pain level. Experience has shown that you cannot achieve the secondary goal without addressing the primary goal.

- Physical therapy: Assess function, improve general conditioning, provide focused intervention to improve pain and function.
- Pediatric psychology: Most patients will benefit from evaluation by a pediatric psychologist. It is important to communicate that this does not mean the patient does not have "real" pain. It is a natural consequence of chronic pain that patients will experience some behavioral impact that can be helped by either general support, or focused intervention such as biofeedback.
- Medical intervention: A full discussion of the treatment of chronic pain is beyond the scope of this chapter, but many patients will benefit from medications such as antiepileptics (gabapentin) and/or antidepressants (amitriptyline), depending on the type of pain. As noted, regional anesthesia may be indicated in specific circumstances.

Perhaps the most important "intervention" any provider can provide is to acknowledge the patient's pain and the significant impact it is having on the patient's life, and the family's life. It is also helpful to start the conversation by stating that there is usually no magic cure, but there has been considerable success in helping chronic pain patients with a rehabilitation/multidisciplinary approach.

## TAKE HOME POINTS

- The anesthesiologist is in a unique position to act as a resource to other providers when they are faced with managing a pediatric patient with chronic pain.
- While there are many potential pitfalls, patients with chronic pain can be safely and effectively managed in the perioperative period by incorporating adjuvant medications and regional analgesia.
- Management of chronic pain outside the operating room is most effective utilizing a multidisciplinary approach.
- The anesthesiologist should not hesitate to consult with pain physicians when faced with complex patients, whether in the perioperative setting or outside the operating room.

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# “But, It’s Just an Herb!” Avoiding Problems Resulting From Nontraditional Pain Medications in the Pediatric Population

Cherie Long, MD and Jeffrey L. Koh, MD MBA

The use of complementary and alternative medications (CAM) in the pediatric population seems to be here to stay. These treatments and medications continue to gain popularity because of perceived benefits in both acute pediatric disease and chronic pediatric illness. CAM can be defined into five categories: alternative medical systems, mind–body interventions, biology-based therapies (including dietary supplement, herbal, and other “natural” medications), manipulative and body-based methods, and lastly, energy therapies.

How common is the use of CAM for pediatric patients, especially herbal and/or homeopathic medicines? Pretty common! For instance, in the pediatric emergency department, Pitettie et al. found 12% of caregivers used some sort of CAM for their children. Another study found that up to 45% of caregivers had given their child herbal or natural remedies in the past year. A multicenter study done by Everett et al. across five US pediatric hospitals has estimated that 3.5% of pediatric surgical patients were given herbal or homeopathic medications 2 weeks prior to surgery. A trend toward the use of CAM is particularly common in patients with chronic pain and it is understandable why a concerned parent or distressed caregiver would start down this road.

## Chronic Pain and Herbal Therapy

Chronic pain and related symptoms are a common reason for patients and their caregivers to try CAM, with certain herbal remedies most commonly used for specific types of pain. Unfortunately, significant anesthetic implications are not rare, as listed below.

## Chronic Headaches

It is estimated that by the age of six, 39% of children have suffered from a headache. Several herbal remedies, as well as vitamins and related compounds, have been suggested for use for headaches in adults, but few have been subjected to clinical trials in children. These remedies continue to be recommended on patient education websites. Such remedies include feverfew, butterbur, riboflavin and magnesium, and coenzyme Q10.

- **Feverfew** or Tanacetum parthenium is thought to prevent migraines by preventing prostaglandin production.
- **Butterbur's** effects to prevent the incidence of headaches stem from its anti-inflammatory and spasmolytic (muscle relaxant) properties. One study found that 77% of participants of ages 6 to 17 reported at least a 50% reduction in the frequency of their migraine attacks by taking 50 to 150 mg (depending on age) of standardized butterbur for 4 months. Butterbur may also be useful in patients suffering from asthma and help alleviate hay fever and allergies.
- One study found that that up to 33% of children have a deficiency in CoQ10, and if supplemented, may decrease the frequency of migraines.

## Chronic Functional Abdominal Pain

The incidence of abdominal pain varies across countries, although the prevalence of weekly pain ranges from 10% to 23%. The most commonly used herbal medications are ginger, peppermint oil, licorice, fennel, and chamomile.

- Several studies have found **ginger** to have anti-inflammatory and analgesic properties similar to nonsteroidal anti-inflammatory drugs (NSAIDs). Ginger has also been found to lower muscle pain "intensity" and significantly reduce nausea and vomiting in children subjected to chemotherapy for cancer.
- A single, randomized control trial compared **peppermint oil** to placebo in 50 children with irritable bowel syndrome. The study found that peppermint oil was a more beneficial treatment for pain than either fiber and the pharmaceuticals famotidine and pizotifen (serotonin antagonist).
- **Licorice** has antispasmodic, anti-inflammatory, expectorant, laxative, and soothing properties.
- **Fennel** contains anethole, a volatile oil that can stimulate digestive juices and help tame inflammation.
- **Chamomile** also possesses anti-inflammatory and sedative properties, which may help decrease intensity of abdominal pain. It also relaxes the muscles of the digestive tract easing peristalsis.

## Musculoskeletal Pain

Incidence varies, but studies show that the weekly prevalence of musculoskeletal pain in pediatrics range from 8% to 32%, and is most common in the lower extremities and neck. The most common herbal remedies for natural pain relief include topical capsaicin, ginger, feverfew, turmeric, and "devil's claw."

- **Capsaicin** is derived from hot chili peppers, and is thought to work by deleting a compound, substance p, that conveys pain sensation from the peripheral nervous system to the central nervous system. It is used topically.
- **Ginger** is thought to help with joint pain due to phytochemicals which help stop inflammation.
- **Feverfew**, as discussed above, is also used for rheumatoid arthritis.
- **Turmeric** can relieve arthritis pain due to a chemical called curcumin, which has anti-inflammatory properties.
- **Devil's Claw** is a South African herb that may be helpful in managing arthritis and low back pain, but lacks quality research.

The American Pain Foundation was a patient advocacy group that was shuttered after controversy and Congressional inquiry. This group had also listed Ginseng for fibromyalgia, Kava Kava for neuropathic pain and tension headaches, St. John's wort for sciatica, arthritis and neuropathic pain, and Valerian root for spasms and muscle cramps (Table 212.1).

**Table 212.1 ■ Herbal Medications and Their Anesthetic Implications**

| Herbal Medication | Anesthetic Implications |
|---|---|
| Feverfew | Increases risk of bleeding due to inhibition of platelet activity. Avoid in patients taking warfarin, NSAIDs, aspirin, or Vitamin E. Can also decrease bioavailability of iron preparations. |
| Ginger | Side effects range from hyperglycemia to prolonged bleeding due to thromboxane inhibition. |
| Licorice | Large amounts may cause mineralocorticoid side effects (by inhibiting 11-β-hydroxysteroid dehydrogenase), resulting in hypertension, electrolyte imbalances and hypokalemia. Avoid taking with NSAIDs. |
| Ginseng | Increases risk of bleeding, and can interact with |

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| | warfarin and lowers blood sugar |
| Kava Kava | May increase sedative effects of anesthesia. Can increase antiepileptic medications requirements |
| St. John's wort | May alter metabolism of drugs such as warfarin, steroids, protease inhibitors, SSRIs/antidepressant, and cyclosporine |
| Valerian root | Could increase effects of sedatives. Long term, could increase anesthetic requirement. Withdrawal symptoms are similar to valium addition |
| Garlic | Increase risk of bleeding, especially when combined with other anticoagulants |
| Ephedra | Increases risk of MI, arrhythmias, stroke and interacts with other drugs. Can cause profound hypotension that responds to phenylephrine, not pseudoephedrine |
| Echinacea | Immunostimulatory properties, thus should be avoided in those on immunosuppressive therapies or are transplant patients. Long term usage can cause immunosuppression, with risks of impaired wound healing and opportunistic infections. |
| Ginkgo | Increases risk of bleeding, especially spontaneous intracranial bleeding and hyphema |

## A Quick Note on Herbal Contaminants

**Herbal medications are thought to only contain natural herbal components, but, according to one study in Singapore, 2% of analyzed herbals contained heavy metals.** The most common toxic heavy metal was mercury (67%), followed by lead (19%), arsenic (16.7%) and copper ((2.4%). In the same study, 1.5% of analyzed herbs contained conventional western medications such as antihistamines, NSAIDs, analgesic antipyretics, corticosteroids, sympathomimetics, bronchodilators, diuretics, and hypoglycemic agents. To the anesthesiologist, these have obvious consequences, such as perioperative hypoglycemia due to oral hypoglycemia contaminants, as well as adrenal suppression resulting in perioperative hypotension, electrolyte disturbance, impaired wound healing, and immunosuppression.

## Do Herbals Really Cause Adverse Events or Is It All

## Theoretical?

Lee et al. composed a blinded study of 601 patients in Hong Kong that found that, when compared with nonusers, those who took herbal medications in the 2 weeks prior to surgery were more likely to have preoperative events. These included one incidence of a prolonged activated partial thromboplastin time, and three reports of hypokalemia. On the other hand, the authors did not find a significant association between the use of any herbal medication and occurrence of either intraoperative or postoperative events.

Ernst et al. did a systematic review of 26 cases reporting the adverse outcomes of unconventional medications in children. **Those events that involved herbal medications included bradycardia, brain damage, cardiogenic shock, diabetic coma, encephalopathy, heart rupture, intravascular hemolysis, liver failure, respiratory failure, toxic hepatitis, and death.** There was a high degree of uncertainty regarding the causal relationship between therapy and adverse event, thus no definitive conclusion could be made.

Lastly, the WHO monitoring center reported 8,985 case reports of adverse events associated with herbal remedies from 1968 to 1997. Approximately 100 of these events occurred in children less than 10 years of age.

## What About Neuraxial Blocks and Herbal Medications?

As stated above, herbals such as feverfew, ginger, garlic, ginseng, and gingko can all potentially increase the risk of bleeding, and one would assume, increase the risk for an epidural/spinal hematoma if undergoing neuraxial anesthesia. However, there is no direct evidence in the literature of a neuraxial hematoma in a patient on the herbal medications. The 2015 ASRA guidelines state, "herbal drugs, by themselves, appear to represent no added significant risk for the development of spinal hematoma in patients having epidural or spinal anesthesia." On the other hand, combining herbals with other forms of anticoagulation may increase bleeding complications in these patients, and the decision to proceed should be made on a case-by-case basis.

In all, it is difficult to interpret these results due to causal relationships. Also, patient underreporting makes this distinction even more difficult. As a result, the ASA has recommended all herbals be stopped for at least 2 weeks prior to surgery, in an attempt to avoid these potentially adverse events.

## Common Pitfalls With Herbal Medications

- Surgeons should ask their patient about herbal medications or multivitamins, but let's assume they haven't. Keep working with the surgeons to incorporate herbal medication queries into their history-taking, and remember that the preoperative

physician assistants and nurse practitioners may be amenable to discussions and informational exchanges, as well. Let them know that the new ASA guidelines recommend discontinuation of all herbal medications 2 weeks prior to surgical intervention, then remind them again.

- Regardless of who has already asked what, the anesthesiologist should ask her patients about alternative medications in her own preanesthetic evaluation. It is important not to forget to question the breastfeeding mother's intake due to the potential effects on her infant.
- If you haven't already, start studying the common herbs and their drug interactions.
- Consider possible contaminants found in herbals and expand differentials to these ingredients if operative problems arise.
- If a patient is on any herbal remedy on the day of surgery, the patient should be advised of any potential side effects and intraoperative complications and what plans you have to avoid and mitigate them. The surgeon, anesthesiologist, and patient should be in this discussion together, especially if there is a question about proceeding with the case.
- If the procedure has an increased potential of blood loss, or if the patient is susceptible to increased blood loss, keep alternatives in mind. With consultation of patient and surgeon, some elective cases may be cancelled.

In case you were wondering, yes, we ourselves have cancelled at least one case due to the concomitant use of herbal medications. The case was a neurologic surgical procedure and the patient (as we recall) was on ginkgo. The concern, of course, was for bleeding, and the cancellation was not of a particular anesthetic procedure, but rather, we cancelled the entire case and did the case several weeks later when the patient had been off all herbal medications.

So, the best advice we can give the practitioner facing the confirmed or suspected use of herbal medications in the immediate preoperative period is that it's okay to be a little afraid of a possible complication (especially a bleeding complication), to say just that, and to recommend a change in anesthetic technique based on your personal experience and judgment.

## TAKE HOME POINTS

- All patients should be asked if they take any CAM prior to surgery, at least once, if not twice.

- Current ASA guidelines suggest discontinuing all herbal medication for a 2-week period prior to surgery.
- Anesthesiologists should be aware of potential adverse effects of commonly used herbal medications, including bleeding (feverfew, ginseng, garlic); sedation (kava kava, Valerian root); hypokalemia (licorice), and other metabolic effects.
- Start learning the herbal drug–drug interactions!
- Pay attention to your own level of discomfort and concern when proceeding with an anesthetic for a patient on recent or high-dose herbal therapy and don't forget to communicate!

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# Okay, There Are Herbals, but What About Those "Other Herbals?"

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The recreational use of cannabis has increased drastically since the 1980s. Ten states and Washington DC, at the times of this writing have legalized the recreational use of cannabis – Colorado, Alaska, Oregon, California, Massachusetts, Nevada, Washington, Michigan, Vermont, and Maine. Also, 33 states and Washington, DC have legalized the broad use of medical marijuana. Only a few allow medical marijuana in pediatrics, but laws are specific for seizure disorders.

Pediatric medical marijuana is often used when conventional medical treatments fail. The most common conditions include epilepsy, cancer, autism, posttraumatic stress disorder, cerebral palsy, muscular disorders, and cystic fibrosis. Medical marijuana, as opposed to recreational marijuana is often used in the form of oils and tinctures. Specific strains such as "Charlotte's Web" have been specifically grown for children.

The most active of the 61 cannabinoids in cannabis is tetrahydrocannabinol (THC). THC is responsible for the majority of cannabis' therapeutic effects. Cannabinoids have analgesic, muscle-relaxant, and anti-inflammatory properties. THC is a potent antiemetic, appetite stimulant, and analgesic. In addition, cannabis exerts anxiolytic, hypnotic, and antidepressant effects, as well as some anticonvulsant action. Despite its potential medical uses, it has been found to interact poorly with anesthesia. Many of the alternative forms of consumption (oils, tinctures) have not been well studied.

## Anesthetic Considerations of Marijuana

- Cannabis may enhance the sedative-hypnotic effects of other CNS depressants, such as opioids, barbiturates, benzodiazepines, and alcohol.
- Cannabis smoking is similar to the impairment in lung function as tobacco smoking.
- The cardiovascular effects of cannabis may interact with heart rate or blood pressure.
- Small doses of cannabis have been reported to lead to tachycardia. In high doses, sympathetic activity appears to be inhibited with resultant bradycardia and hypotension. The hypotension is usually responsive to fluids.

- In cases of acute intoxication, it is best to avoid medications that increase heart rate, such as ketamine, pancuronium, atropine, or epinephrine. Also, more anesthetic is usually required due to greater catecholamine release.
- Chronic abuse usually requires less anesthetic due to catecholamine depletion.
- THC depresses the body's temperature regulation, making the patient more prone to hypothermia.
- THC depletes the stores of acetylcholine in the synapses by as much as 50%, thus increasing the likelihood of anticholinergic effects.
- One should expect the possibility of psychiatric side effects or withdrawal symptoms in patients, both during induction, and emergence.

Although not well understood, it appears cannabis withdrawal can occur and has similarities to alcohol and opioid withdrawal. Signs and symptoms include dysphoria, restlessness, insomnia, anxiety, irritability, anorexia, muscle tremor, increased reflexes, and several autonomic effects. Withdrawal can occur with daily THC doses of 180 mg (one or two "good-quality" joints), for as little as 11 to 21 days. Fortunately, cannabis withdrawal is short-lived and usually mild, but can confuse the clinical picture for the anesthesia provider. Administration of dronabinol (oral THC) may mitigate the symptoms of withdrawal, but there is no clear information about dosing in this setting.

## TAKE HOME POINTS

- All patients should be asked if they take any CAM prior to surgery.
- Current ASA guidelines suggest discontinuing all herbal medication for a 2-week period prior to surgery.
- Anesthesiologists should be aware of potential adverse effects of commonly used herbal medications.
- Withdrawal symptoms can be seen in patients who take cannabis regularly and may manifest itself in the postoperative period.

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# Pitfalls in Pediatric Sedation

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"By failing to prepare, you are preparing to fail."

—Benjamin Franklin

As the demand for pediatric sedation grows, the anesthesia provider will face a number of new and challenging situations. Several societies provide policy statements and guidelines intended to give anesthesia and nonanesthesia providers the framework necessary to develop safe-sedation practices. These include the American Society of Anesthesiologists (ASA), the American Academy of Pediatrics (AAP), and the Society for Pediatric Sedation, among others. The goal is to standardize the quality and safety of pediatric sedation.

To that end, this chapter intends to help you understand what the pitfalls are and how to best avoid them. To do this, you must know your patient and why he/she needs sedation; you must know the risks and be prepared, including getting informed consent; and you must have a well-thought sedation plan (no winging it!), as well as postsedation discharge criteria and instructions for caregivers.

## Patient and Procedure

You will be asked to sedate patients for a variety of reasons, including surgeon/proceduralist preference, previous failure under minimal or moderate sedation by nonanesthesia providers, and presence of significant patient comorbidities. Therefore, you will need to determine what level of sedation is best for your patient for the given procedure. One of the most common pitfalls is not having clear goals for the procedure. For example, Is the problem anxiolysis? Do we need immobility? Is this a painful procedure that requires analgesia? Are there special goals for emergence, besides being timely and smooth?

To get a grip on your sedation goals and plan, you must first get a grip on the patient's history. Remember that high-risk populations are those patients with ASA classification of III or greater, obstructive sleep apnea (don't forget to ask about

snoring!), premature infants who are still less than 60 weeks PCA (at risk for apnea for 12 to 24 hours), and patients with history of neuromuscular disease affecting respiratory function. In addition, knowledge of previous sedation history, and whether or not the patient experienced an adverse event in the past may help you formulate a sedation plan, especially if you are able to review a previous anesthetic record.

Next, think about the physical examination. **Examination of the airway and body habitus are the two most important components that help determine a sedation plan.** For example, congenital abnormalities like micrognathia or midfacial hypoplasia can increase the incidence of airway obstruction on induction. An obese child with a thick neck is not necessarily difficult to intubate, but certainly is at risk for upper airway obstruction and hypoventilation.

When obtaining informed consent, the parent or guardian interview should include the risks associated with sedation and possible alternatives. Make sure you give your patient's caregiver explicit instructions on how to keep their child safe post procedure. In the event that you are asked to "bail out" a failed sedation, **do not** be afraid to take a step back and reassess the situation following a review of the history, physical, and sedation administered before embarking on a new course of action.

When performing a risk assessment, as previously stated, an ASA physical status of III or greater has been shown to correlate with increased risk of sedation-related adverse events. The AAP encourages consulting with a pediatric anesthesiologist for a patient that is ASA III or more.

## Risks and Preparation

Anticipate adverse events! And classify as an adverse event anything that might negatively affect outcome or delay recovery. You will most likely be sedating a child in an offsite location, so knowing where the crash cart is and whether any special emergency drugs are readily available, is of utmost importance. For example, if there is a chance that you may convert the sedation to general anesthesia, make sure you know how and where you can obtain dantrolene. Offsite locations are also frequently not equipped to our stringent specifications and needs, so you might find yourself in an educational role, that is, how should we say it, "working constructively" with nonanesthesia personnel in order to ensure an environment that's safe for sedation.

The commonly used acronym for preanesthesia preparation for children is the same as for adults: SOAPME.

S—Suction catheter and functioning suction apparatus: don't forget that NPO guidelines still apply—2 hours for clears, 4 hours for breast milk, 6 hours for formula, nonhuman milk or light meal, 8 hours for heavy meal. Loss of protective airway reflexes

during deep sedation increases the risk of pulmonary aspiration.

O—Oxygen supply: supplemental $O_2$ decreases the incidence of hypoxemia. It does not, however, prevent hypoventilation.

A—Airway equipment: it is not possible to stress this too strongly when working with children. **A cardiac arrest in a child is most likely to be caused by a respiratory event, not a cardiac one**. Have oral and nasopharyngeal (N-P) airways in multiple sizes, and know how to choose the appropriate size for your patient (Hold the N-P airway to the side of the face; it should extend from the tip of the nostril to the tragus. The oral airway should extend from the mouth to the angle of the mandible when held to the side of the face), direct laryngoscope, stylets, endotracheal tubes, nasal cannula, face mask, bag-valve mask, and other equivalent airway equipment.

P—Pharmacy: basic advanced cardiac life support medication and reversal agents for emergency situations.

M—Monitors: capnography, pulse oximetry, noninvasive blood pressure monitoring, and EKG. They are important adjuncts to your own vigilance (eyes and ears) and you must know how to interpret them.

E—Equipment: defibrillator, and other special equipment.

Recognizing and relieving airway obstruction, whether it's caused by pharyngeal obstruction or laryngospasm, is the key to avoiding an airway disaster. Don't be afraid to halt a procedure in order to check on your patient in a timely manner if you suspect hypoventilation or desaturation. Just because you can hear your patient snoring does not mean everybody is okay!

## Goals and Plan for Procedural Sedation

Having a clear understanding of your goals is the key to successful procedural sedation. This includes avoiding longer-acting medications for brief procedures. It is important to gain expertise with the technique of titration of drugs to effect so as to avoid oversedation and undersedation, and minimize side effects. Patient comfort can be addressed by simply reducing anxiety and/or pain. Do not make the mistake of giving a sedative when an analgesic is needed, and an analgesic when a sedative is needed. You may end up still needing to give the other one and oversedating your patient this way. Maintaining cardiopulmonary function and managing complications effectively can ensure patient safety. The concept of drug synergy is of prime importance; small doses of two different drugs are not just additive, but synergistically greater, leading to a more potent effect, and a higher incidence of unwanted effects like apnea. Synergy can also be employed to our advantage, such as using alfentanil with propofol for a painful procedure to minimize the total dose of propofol, allowing the patient to emerge faster

from sedation. Providing adequate sedation will optimize conditions for the procedure and improve efficiency. Finally, do not discharge your patient until preprocedural function and physiologic level are achieved, and discharge instructions are reviewed with caregivers.

Anxiolytic, hypnotic, and analgesic agents are commonly used for pediatric sedation. The level of stimulation anticipated for the procedure will help determine which medications are most suitable. For example, you don't necessarily need to use narcotics if pain or discomfort is not expected, and this may be desirable in sicker patients or those with OSA.

Propofol is the number one choice of anesthesia personnel since its hypnotic, antiemetic, anxiolytic, amnestic, and anesthetic properties make it an ideal drug. Quick onset of action and rapid emergence make it especially useful in children, though significant respiratory depression and reduction in airway tone require proficiency in advanced airway skills. Its properties make it desirable as the sole agent for nonpainful procedures, and it has been used successfully for MRI at moderate infusion rates of 150 to 200 mcg/kg/min.

Midazolam is the most commonly used benzodiazepine in the pediatric population. It can be administered via intravenous, oral, nasal (irritates the mucosa), rectal, and intramuscular routes. PO midazolam at 0.5 mg/kg can be used for a procedure that is nonpainful and does not require absolute immobility. Intravenous midazolam at 0.025 to 0.5 mg/kg provides a more predictable and faster onset. Paradoxical reactions to midazolam can occur.

Chloral hydrate is one of the most commonly used hypnotic agents for nonpainful procedures in children. Because of its hypnotic effect and convenient routes of administration, it is most commonly employed by nonanesthesia providers. Given the other medications at your disposal, especially those with faster onset, it is unlikely to prove useful to the anesthesia provider. A 50 to 75 mg/kg dose, either via oral or rectal route, is recommended for deep sedation. The use of chloral hydrate is limited in painful procedures because of patient movement and agitation despite appearing sedated.

Dexmedetomidine is a highly selective alpha-2 adrenergic agonist that has hypnotic, anxiolytic, and analgesic properties. Compared to other sedating agents, it results in less respiratory depression. As a result, its off-label use in pediatric procedural sedation has grown tremendously, especially for nonpainful procedures. It can also result in significant bradycardia and hypotension, so slow infusion is recommended. While intravenous infusion is the most common route of delivery, IM, buccal, and intranasal delivery have also been described. When given intravenously, 0.5 to 1 mcg/kg given over 10 minutes followed by an infusion of 0.2 to 1 mcg/kg/hr for nonpainful

procedures, is an effective sedative, but will not reliably produce prolonged immobility, say for MRI, unless the dose is considerably higher. Dexmedetomidine as the sole agent for MRI is described, but requires a higher dose, and a significant portion of children needed repeat boluses or additional medications.

Ketamine is an N-methyl-D aspartate (NMDA) receptor antagonist that provides excellent analgesia. Due to its dissociative effects, it is commonly administered in combination with midazolam, providing effective conditions for patients undergoing moderately painful procedures. It can be given via intravenous and intramuscular routes, the IM dose being higher than the IV. It can also be initially given PO. It is a favorite in the ED where painful procedures are frequently performed, and has the added benefit of preserving cardiorespiratory function. The nasal route provides adequate sedation and anxiolysis, but only at much higher doses than for IV or IM in one study involving laceration repair. A wide range of doses is used in clinical practice, but usually an initial dose of 1 to 2 mg/kg IV or 3 to 4 mg/kg IM, followed by 0.5 mg/kg IV repeated every 2 to 3 minutes as needed is effective. Ketamine should be used cautiously, perhaps not at all, in patients with intracranial hypertension and systemic hypertension, and is contraindicated in patients with neuropsychiatric disorders. Because of hypersalivation, consider administering an antisialagogue.

Nitrous oxide is a useful adjuvant for IV placement and dressing changes, and some hospitals have credentialed nursing staff to administer nitrous (30% to 50% in oxygen) on the wards.

Opioids are excellent adjuncts for procedures that are painful and require the patient to stay still. Fentanyl, alfentanil, and remifentanil are the most commonly used opioids for this purpose, and small doses are usually sufficient. Fentanyl 0.5 to 2 mcg/kg IV or remifentanil 0.0125 to 0.2 mcg/kg/min usually results in good analgesia. Remifentanil has the benefit of having a quick onset and short elimination half-life and clearance that prevent drug accumulation. Its profound respiratory depressive effects, however, warrant extreme caution.

## Postsedation Discharge Criteria

Discharge criteria as recommended by AAP/ASA:

) Stable vital signs.
) Pain under control.
) A return to the level of consciousness that is similar to the baseline for that patient.
) Adequate head control and muscle strength to maintain a patent airway.
) Nausea and/or vomiting should be controlled and the patient should be adequately hydrated.
) Responsible adult for discharge.

') Written instructions and emergency number.

When instructing caregivers, an emphasis should be placed on watching carefully for signs of respiratory distress, such as snoring in a child that doesn't usually snore. Children should not be left unattended in a car seat, and a sleeping child should not be left alone. Infants and toddlers are particularly at risk and have had fatal postdischarge respiratory obstruction when given longer-acting sedatives. Their heads can fall forward and obstruct the airway unnoticed. Furthermore, caregivers should exercise caution when allowing children to participate in activities requiring coordination for up to 12 to 24 hours, or allowing them to swim or bathe unattended.

## TAKE HOME POINTS

- Have a basic understanding of the pediatric cardiorespiratory system and have rescue medications and equipment readily available.
- Develop familiarity with frequently used medications, including reversal agents. It may be a good idea to pick a few drugs with different effects and know them well.
- Monitor, evaluate, and promptly intervene throughout the procedure and postprocedure until patient meets discharge criteria.
- Acknowledge self-limitation, especially with high-risk patients, and consult a pediatric anesthesiologist when necessary.
- Remember that combining drugs means reducing the doses of each and synergistic unpredictable effects!

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# Pitfalls of Pediatric Anesthesia for International Service Missions

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## Pediatric Anesthesia for International Voluntary Services

Every year many physicians and other health care providers travel to developing countries to deliver a wide variety of medical services. Often these programs involve performing surgical procedures and many are targeted toward pediatric patients that would otherwise not have access to care. Anesthesia providers serve a vital role in assuring these patients receive safe, appropriate care as part of these valuable medical service projects. It is important to conduct a systematic assessment of the proposed trip to ensure that the appropriate personnel, equipment, and medications will be available. This chapter will cover some recommendations to help avoid common errors that can occur during medical service trips.

## Choose Your Adventure Wisely

Medical service organizations vary widely, so it is important to find a group that matches your professional experience and personal goals. When evaluating a trip, one should consider:

- Specific patient populations served
- Geographic location and access to resources
- Political stability of the host country
- Exposure of medical providers to communicable diseases and other health conditions
- Affiliations of the sponsoring organization, including any religious partnerships

Organizations may focus on teaching, clinical care, or both. Some trips have limited interactions with local health care providers, while others work alongside the existing health care system. Each participant has the responsibility to thoroughly examine the parameters of the mission group and question if it is feasible to work in the expected

conditions. In addition to obtaining a good understanding of the organization, one must have knowledge of the culture of the host country as this may impact the volunteers and the goals of the trip. Countries may require:

- A visa.
- Proof of vaccinations.
- Documentation of professional education.
- Dress requirements in accordance with cultural or religious practices.
- Regulations pertaining to volunteer service missions, including limitations on the importation of medications and medical equipment.

## Know Your Team Members

A team meeting conducted before the initiation of clinical care should be used to outline:

- Goals of the program.
- Targeted patient population.
- Anticipated surgical procedures to be performed.

Each team member should communicate:

- Clinical experience.
- Experience with international service projects.
- Anticipated role in the team.
- Work expectations.
- Physical restrictions and limitations.

From this meeting the anesthesia provider should determine if there will be assistance, such as anesthesia technicians, or if he or she will be working independently. The anesthesia provider should develop an in-depth understanding of the experience and comfort levels of the nurses that will work in the postanesthesia care unit (PACU), especially in regard to management of pediatric patients. This will help the anesthesia provider plan how the patients should be safely transported to and managed in the PACU.

## Find the Right Patients

Patient criteria should be established before the screening clinic begins. The criteria should be based on the:

- Goals of the program
- Skills of the providers
- Resources of the facilities

- Availability of follow-up care after the team departs

In addition to a standard preoperative evaluation, patients in developing counties should be evaluated for common conditions such as anemia, parasites, reactive airway disease, tuberculosis, congenital or rheumatic heart disease, and chronic infections. Nil per os (NPO) guidelines should be thoroughly explained to each patient to avoid any day of surgery cancellations. **Preoperative fasting guidelines published by the American Society of Anesthesiologists (ASA) should be followed**. Before discussing NPO guidelines and surgical timing with patients, one may need to gain some understanding of how the local culture measures time. In some locations, patients may not have easy access to watches or clocks, so other indicators of the time of day may need to be referenced.

When designing the surgical schedule, younger patients should be scheduled early in the day. This minimizes their NPO duration and provides more time for them to be monitored in the PACU. The complex cases should be scheduled early in the trip, thus allowing for more follow-up time should complications arise. However, the first day of surgery should include uncomplicated cases that are scheduled for additional time. This allows for the management of unanticipated problems that can be encountered on the first day.

## Equipment Pitfalls

For many international volunteer programs, the anesthesia provider must adapt to using the anesthetic equipment available in the host country. A complete investigation of all equipment must be done before delivering anesthesia care. Specifically, one should confirm the presence of:

- A pressurized oxygen source.
- Soda lime for partial rebreathing systems.
- Oxygen analyzers.
- Scavenging systems.

**Often there is only one vaporizer available.** Isoflurane can be used in a halothane vaporizer as they have similar vapor pressures, although isoflurane cannot be used for an inhalational induction.

**Nonrebreathing systems should be brought for every trip, as it is not uncommon for anesthetic machines to be unavailable or nonfunctional.** The Mapleson D and its Bain modifications or the Mapleson F (Jackson Rees) can be used for either controlled or spontaneous ventilation. The Mapleson A (Magill) is very efficient for spontaneous ventilation. The main disadvantage is that these systems will require high fresh-gas flows, which will quickly consume oxygen sources and vapor supplies. **There should**

**be enough self-inflating ventilating bags available so that if the oxygen supply fails, each anesthetized patient can be hand ventilated without an oxygen source.** There should also be one available in the PACU for emergencies.

A well-equipped resuscitation kit is a required item for each mission. It should include appropriately sized items for pediatric patients of all ages. The PACU can be a centralized location for storage of the kit, assuming the PACU is located close to the operating rooms. It should include a self-inflating positive-pressure device (e.g., Ambu bag), supraglottic airways, oral airways, nasal trumpets, intubation supplies, resuscitative drugs, and a defibrillator.

## Don't Forget the Monitors

Whenever possible, anesthesia providers on international service trips should follow the ASA's standards for monitoring, including continuous evaluation of oxygenation, ventilation, and circulation. If general anesthesia is used, there should ideally be:

- Pulse oximetry
- Electrocardiography
- Continuous capnography
- Measurement of pulse and blood pressure in at least 5-minute increments

If access to electricity is limited, some monitoring can be done using precordial stethoscopes, manual blood pressure cuffs and keeping a finger on the patient's pulse and a hand on the breathing bag. Temperature monitoring should be available and utilized. Hypothermia in the operating room is often a concern, but in many developing countries the operating rooms do not have air-conditioning and hyperthermia may also become a problem. For patients that are mechanically ventilated, a disconnect alarm should be present and activated. The anesthesia team should plan to provide these monitors, as they may be unavailable or nonfunctional in the host country.

## Use Spontaneous Ventilation

General anesthesia is commonly used during international service trips and since a mechanical ventilator may be unreliable or unavailable, it is preferable to keep patients spontaneously ventilating. For pediatric patients, a peripheral intravenous line is often placed after an inhalational induction, which is usually done with sevoflurane. Children can often be intubated without neuromuscular blocking agents by increasing their depth of anesthesia with propofol or sevoflurane. One can also blunt their response to laryngoscopy with narcotics. Routine use of succinylcholine in the pediatric population is not recommended because of concerns for developing masseter spasm, causing muscle rigidity, and triggering malignant hyperthermia. Furthermore, in patients with

undiagnosed neuromuscular disorders, succinylcholine can produce severe hyperkalemia that can induce life-threatening arrhythmias. However, succinylcholine should be readily available in every operating room and the PACU to treat laryngospasm.

## Regional Anesthesia Is Your Friend

Patients can be evaluated to determine if they are candidates for regional anesthetic techniques, depending on the surgical procedure. Regional anesthesia can:

- Decrease the amount of general anesthetic required.
- Help smooth emergence.
- Shorten turn-over time.
- Provide better postoperative analgesia than general anesthesia used alone.

A single-shot caudal injection of 0.25% bupivacaine or 0.2% ropivacaine is an excellent regional technique for procedures involving the lower extremities, the lower abdomen or pelvic region. For operations involving the lips, the infraorbital nerve can be blocked transorally or percutaneously. Peripheral nerve blocks, including femoral, popliteal and axillary, can be done quickly using a portable nerve stimulator. Using ropivacaine or bupivacaine for peripheral nerve blocks can provide several hours of postoperative pain control. Surgeons should infiltrate the wound with local anesthetic whenever possible to provide additional postoperative pain relief.

## Remember a Postoperative Care Plan

A plan for postoperative analgesia, fluid administration, and discharge criteria should be developed with the entire team before the first day of surgeries. A multimodal approach to analgesia can be employed in order to minimize the use of opioids, which can cause sedation, respiratory depression, and prolonged recovery times. In addition to regional anesthetic techniques, opioid requirements can be reduced by using nonopioid analgesics such as:

- Acetaminophen
- Nonsteriodal anti-inflammatory drugs (NSAIDS)
- Ketamine

In addition to oral or intravenous administration, acetaminophen can be given rectally after induction of general anesthesia. Nalbuphine, a partial opioid agonist–antagonist, can provide good analgesia with only mild sedation when given in intermittent doses. One may choose to avoid neuraxial opioids since they can produce variable degrees of respiratory depression in the postoperative period. Also, most

pediatric patients will be discharged home on the day of surgery.

Nurses with PACU experience should staff the PACU area at a minimum ratio of one nurse for every two patients. More staffing may be necessary for some pediatric or airway cases. For every two PACU beds there should be at least one oxygen cylinder with a regulator and one pulse oximeter. Patients can be discharged from the PACU once they are awake, have baseline oxygen saturation on room air, are breathing comfortably, and have an adequate pain control. Before the patient leaves the PACU, discharge instructions and a follow-up care plan should be explained to the patient and/or the family in their native language. Follow-up care includes having appropriate staff available for early postoperative care and having local staff designated for late routine postoperative care and management of complications that arise after the visiting team has departed. The local staff should also have the ability to contact the visiting medical team members involved with the patients' care.

## TAKE HOME POINTS

- Before agreeing to participate in a mission trip, thoroughly review the mission statement of the organization, geography, culture, working conditions, and the patient population.
- Meet with team members before starting clinical care to review prior experiences, roles and expectations.
- Investigate all anesthetic equipment, especially the anesthetic machine, and confirm presence of self-inflating bags and a resuscitation kit.
- Whenever possible, follow ASA monitoring guidelines, which may require transporting monitors to the host country for use during the mission.
- Establish clear patient criteria and develop a plan for communication of arrival time and NPO time before beginning the patient screening clinic.
- Keep patients spontaneously ventilating to decrease reliance on the available mechanical ventilation devices.
- Use regional anesthesia whenever possible to reduce the use of narcotics while providing good postoperative analgesia.
- Anesthesiologists should be prepared to organize the PACU and provide short-term follow-up care for patients.
- A long-term follow-up care plan should be made before a patient undergoes any surgical procedure.

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# Pediatric Cardiac Arrest Under Anesthesia—Predicting and Preventing the Most Devastating Event of All

Kirk Lalwani, MD FRCA MCR

A simple Child,
That lightly draws its breath,
And feels its life in every limb,
What should it know of death?

("We are Seven"—William Wordsworth, 1770–1850)

The death of a child is a tragedy for everyone involved. Unexpected cardiac arrest may occur in anesthetized children despite optimal care. Several factors are known to be associated with an increased risk of anesthesia-related cardiac arrest in children, and the pediatric care provider should be familiar with them in order to minimize the potential risk.

Following the dramatic decline in anesthesia-related mortality rates over the last 50 years, there has recently been a change in the profile of anesthesia-related cardiac arrest in children. Many studies have identified predictors of increased risk for anesthesia-related cardiac arrest in children, but detailed analysis of the root cause of the arrests is based on data collected in the Pediatric Perioperative Cardiac Arrest (POCA) Registry. POCA was initiated in 1994 as an offshoot of the American Society of Anesthesiologists (ASA) Closed Claims Project to identify the most common causes of anesthesia-related cardiac arrest in children, and to outline strategies for prevention. The initial POCA findings reported details of 150 anesthesia-related cardiac arrests between 1994 and 1997 from 63 North American institutions. The latest report summarized approximately 300 additional cases submitted from 1998 to 2003.

## Predictors of Anesthesia-Related Cardiac Arrest in Children

## ASA Physical Status

The strongest predictor of anesthesia-related cardiac arrest in the POCA study was ASA physical status 3 to 5; this was associated with a 12-fold increase in the risk of cardiac arrest. ASA physical status as a predictor of increased risk is also supported by data from other studies [5, 6].

## Emergency Surgery

Emergency surgery was associated with a threefold increase in risk for cardiac arrest in the POCA study, as well as an increased risk of other anesthetic complications in a landmark French study.

## Age

The risk of anesthetic complications and cardiac arrest in children varies inversely with age. Neonates and infants are particularly at risk. Approximately 50% of all arrests in the POCA registry occurred in infants (<1 year of age), and 15% occurred in neonates (<1 month of age). Of note, however, is that when underlying disease severity was accounted for, that is, ASA status, age alone was not a predictor of death in the POCA study.

## Cardiac Disease

Children with heart lesions such as single ventricle, aortic stenosis, and cardiomyopathy tend to be sicker and at higher risk for cardiac arrest from cardiac causes, and are less likely to survive following cardiac arrest. Cardiac arrest in these children often occurs in the general operating room or cardiac catheterization suite. The incidence of cardiac arrest during cardiac catheterization procedures is also higher than in the general surgical population, especially in infants and during interventional procedures.

## Annual Caseload

The risk of cardiac arrest was higher for providers with a lower annual caseload and/or fewer anesthetics delivered in a year.

# Changing Profile of Anesthesia-Related Cardiac Arrest in Children

## Causes of Cardiac Arrest

Of the 150 cases of cardiac arrest submitted to POCA, 37% were medication related. Two-thirds were likely due to halothane, alone or in combination with other drugs. Medications were also deemed responsible for 64% of arrests in ASA physical status 1

or 2 patients. Based on the analysis of an additional 163 anesthesia-related cases added to the registry, medication-related causes declined from 37% to 20% primarily due to a decline in cardiac depression induced by volatile agents. Cardiovascular causes of arrest are now the most common, increasing from 32% to 36%. In this category, hypovolemia (frequently due to hemorrhage) and hyperkalemia secondary to massive transfusion were the most frequent causes of arrest. Respiratory causes increased from 20% to 27%, with laryngospasm, airway obstruction, inadvertent extubation, difficult intubation, and bronchospasm being the most frequent events. Equipment-related arrests (4%) were commonly due to complications of central venous pressure (CVP) catheter placement. Other assorted causes include children with complex cyanotic congenital heart disease, pulmonary hypertension, myocarditis, prolonged QT syndrome, coronary artery disease, hypertrophic cardiomyopathy, topical vasoconstrictor use, and anaphylactic reactions.

## Demographics of Cardiac Arrest

The percentage of ASA physical status 1 or 2 patients decreased from 33% in 1998 to 27% in 2003, along with the percentage of infants below the age of 1 year (55% to 36%, $p < 0.05$). The POCA investigators attribute these changes to the decline of medication-related arrests, as halothane was often responsible for cardiac arrest in infants who were ASA physical status 1 or 2. The mortality rate for the two time periods did not change (26% vs. 28%), despite the altered profile of reported cases.

## Strategies to Prevent Cardiac Arrest in Anesthetized Children

## Specific Measures

Sevoflurane: Halothane has potent negative inotropic and chronotropic effects that can easily produce profound myocardial depression and a precipitous fall in cardiac output in infants and neonates, particularly when the ability of the halothane vaporizer to deliver concentrations in excess of six MAC multiples is taken into account. The dramatic decline in medication-related deaths in the POCA study has been attributed to the widespread replacement of halothane with sevoflurane for pediatric anesthesia, which has minimal effects on heart rate and myocardial contractility.

Local anesthetics (3.3% of arrests in the initial POCA series): Meticulous technique is essential to prevent inadvertent intravascular injection of local anesthetics that may result in cardiac arrest. Accurate needle placement, careful aspiration prior to injection, the use of epinephrine-containing test doses, continuous ECG monitoring during dosing, and incremental injection of the local anesthetic solution are some of the precautions to

reduce the incidence of this complication. In future, widespread adoption of ultrasound-guided regional nerve blocks may have a significant effect on decreasing the incidence of local anesthetic–related cardiac arrest. Should intravascular injection occur, animal studies and anecdotal case reports suggest that recovery from cardiac arrest may be more likely following ropivacaine than bupivacaine. In addition, the use of 20% Intralipid™ reduces the mortality of local anesthetic-induced arrest in animals. Anecdotal reports in humans suggest it may be clinically useful, and given its innocuous nature, should be available in locations where regional anesthetic blocks are placed.

Hypovolemia: In the POCA study, cardiac arrest due to hypovolemia occurred as a result of the failure to adequately manage hemorrhage, or due to hyperkalemia precipitated by massive transfusion. Inadequate intravenous access and failure of the anesthesiologist to keep up with blood loss were implicated in the hypovolemic arrests that occurred secondary to hemorrhage.

Hyperkalemia related to massive transfusion occurs as a result of potassium leakage from stored red cells into the plasma. It can be minimized by the use of packed red blood cells instead of whole blood, requesting the freshest cells available, and avoiding irradiated blood unless indicated. In high-risk situations such as infants and children requiring more than one blood volume replacement, or where irradiated blood is necessary (e.g., an immunocompromised child), packed red cells should be washed by the blood bank, and intraoperative serum potassium levels carefully monitored.

CVP catheter placement: Cardiac arrest secondary to CVP catheter placement occurred as a result of cardiac tamponade, pneumothorax, or hemothorax in the POCA study. The closed claims study reported that either ultrasound guidance or pressure waveform analysis would have prevented almost 50% of CVP catheter placement–related complications. Routine use of an ultrasound device for placement is strongly recommended to increase success rates and decrease complications.

Succinylcholine: The use of succinylcholine in pediatric anesthesia is indicated for difficult or emergency airway management, and rapid-sequence induction for a full stomach. The routine use of succinylcholine has been responsible for several deaths due to hyperkalemia in children with undiagnosed muscular dystrophies such as Duchenne's. This prompted the manufacturer to change the recommended indications for succinylcholine use in children. Succinylcholine should not be used in children except as described above. Rocuronium provides adequate intubating conditions for rapid-sequence induction, and should be used whenever appropriate.

Muscular dystrophy: Children with progressive muscular dystrophy (Duchenne's and Becker's) are prone to rhabdomyolysis following the use of succinylcholine or volatile

anesthetic agents. A recent editorial has questioned the use of volatile anesthesia (without muscle relaxants) for these patients following the report of yet another death in a child with undiagnosed Duchenne muscular dystrophy (DMD). Since we are unable to predict which children with DMD will develop clinical rhabdomyolysis following volatile anesthesia, it would appear prudent to avoid volatile agents in these children and use an intravenous technique instead. Since 90% of children with DMD have a family history, careful questioning about family members and eliciting the child's developmental milestones may trigger suspicion in asymptomatic children that merits preoperative creatine phosphokinase (CPK) measurement.

## General Measures

) Perioperative environment: The American Academy of Pediatrics has issued guidelines for the creation of a specialized environment for the provision of care for children that encompass provider training, experience, and credentialing, and the availability of appropriate equipment, drugs, and necessary support services such as radiology and intensive care.

) The scope of practice: Anesthetic outcomes for children are improved when anesthesiologists trained or experienced in the care of children are involved. Similarly, for specialized areas such as congenital heart surgery, high-volume centers have lower mortality rates. Therefore, it is appropriate to transfer such patients to referral centers. The United Kingdom recognized this issue many years ago, and has formulated criteria for specialist pediatric centers and providers in the National Health Service. Recently, the American College of Surgeons and the American Pediatric Surgical Association have defined optimal resource standards for children's surgical care, and a voluntary accreditation process for healthcare facilities in the United States has been implemented and is ongoing.

) Continuous quality improvement (CQI): CQI programs include morbidity and mortality conferences and critical incident registries to monitor key quality indicators, identify systematic problems, and implement strategies for the prevention of bad outcomes. Institutional and departmental compliance with professional society guidelines establishes a standard to compare the quality of care with other institutions.

## Conclusion

Rita Mae Brown, social activist and author, once said that "good judgment comes from experience, and often experience comes from bad judgment." Pediatric care providers would be wise to study the collective experience of others afforded by elegant database tools such as POCA to heighten their awareness of the risk factors for cardiac arrest, so as to make good judgments without the burden of personal experience.

## TAKE HOME POINTS

- Beware of high-risk situations such as the ASA 3 to 5 child, emergency surgery, neonates, and infants.
- Beware of children with cardiac disease—especially single ventricle, aortic stenosis, and cardiomyopathy, and interventional cardiac catheterization procedures or catheterization in infants.
- Take care to avoid laryngospasm, and treat it promptly; be vigilant for respiratory obstruction or inadequate ventilation.
- Pay meticulous attention to needle placement and technique for regional anesthesia; use ropivacaine instead of bupivacaine and become proficient with ultrasound-guided blocks.
- Ensure adequate IV access, and assess blood loss relative to blood volume frequently.
- Order fresh or washed packed red cells for infants, and monitor serum potassium levels.
- Place all CVP lines with ultrasound guidance, and don't forget the postoperative chest x-ray.
- Use succinylcholine only when absolutely necessary.
- Avoid succinylcholine and volatile agents with suspected or known muscular dystrophy.

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# SECTION X

# NEUROANESTHESIA

217

# Introduction

Laurel E. Moore, MD

The 1990s was formally designated the “Decade of the Brain” by President George W. Bush. Almost 20 years later, this phrase continues to describe the exciting and rapid improvements in our understanding of cerebral physiology and pathophysiology. Having said this, we still have a long way to go and, because of the complexity of the neurologic system, our understanding lags far behind other anesthesiology subspecialties. But for those of us who love neuroanesthesia, this is part of the thrill of our practice. Neuroanesthesia has long been described by nonneuroanesthesiologists as “hours of boredom interrupted by minutes of sheer terror.” We hope that this section outlining current neuroanesthesia practice can both reduce the “boredom” and temper the exciting times for you.

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# The Neurophysiology You Learned in Medical School Is Always Relevant—Get a Grip on It and Don't Let Go

Laura Patricia Zung, MD and Laurel E. Moore, MD

During your first CA-2 call, the pager goes off for an emergent craniotomy. The patient is a 31-year-old medical resident who presented with an intracranial hemorrhage caused by an arteriovenous malformation. He acutely decompensated, and is now intubated and on the way to your operating room. You call the staff anesthesiologist, who states that the most important part of the anesthetic plan is to implement "neuroprotective strategies." At that moment, you realize you have many questions about what this strategy will entail.

A strong neurophysiology understanding is crucial to the anesthesiologist's ability to care for patients with intracranial pathology. Our anesthetic agents, interventions, and common practices all have the potential to profoundly affect neurologic outcomes. This chapter reviews cerebral blood flow (CBF) physiology and its primary influencing factors, including commonly used anesthetics.

When considering CBF, it is important to remember that the brain is housed within the cranial vault, containing a fixed total volume that can be divided into three categories: brain (80% of intracranial volume: 70% neuronal mass and 10% interstitial fluid), blood (12%), and cerebrospinal fluid (CSF) (8%). The Monro–Kellie hypothesis requires that any increase in one component must be compensated by a decrease in another to prevent a rise in intracranial pressure (ICP). In the healthy brain, CBF easily meets the high demands of cerebral oxygen consumption. Under normal circumstances, CBF is approximately 80 mL/100 g/min in gray matter and 20 mL/100 g/min in white matter, with overall CBF averaging 50 mL/100 g/min. In total, the brain receives 15% to 20% of cardiac output, or 750 mL/min. However, CBF is highly influenced by several well-defined determinants, including cerebral metabolic rate (CMR), autoregulation, cerebral perfusion pressure (CPP), respiratory gas tensions,

temperature, blood viscosity, and of course, anesthetics.

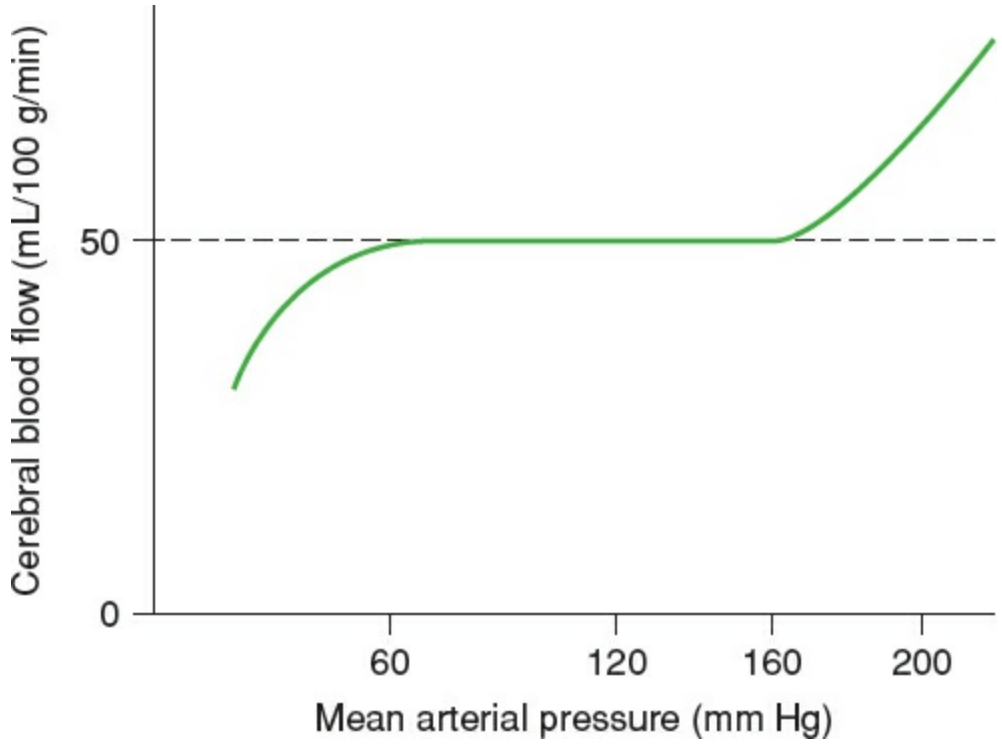


**FIGURE 218.1.** Normal cerebral autoregulation curve.

) **CMR:** CBF is closely aligned to cerebral metabolic demands. Normal CMR for $O_2$ is 3 to 3.8 mL/100 g/min and is greatest in the gray matter of the cerebral cortex. Increases in cortical electrical activity, such as during epileptic seizures, leads to regional CMR increases, which in turn increase blood flow. Conversely, a decrease in CMR, such as during burst suppression, leads to a CBF reduction. This relationship, called flow-metabolism coupling, is a complex process. Though not fully understood, it is thought to involve a local metabolite release affecting cerebral blood vessels.

) **Autoregulation and CPP:** Autoregulation refers to the brain's capacity to maintain a constant CBF over a wide range of mean arterial pressures (MAP). This is accomplished via rapid changes in vascular tone in order to achieve a constant oxygen delivery. The stimulus for these changes is CPP, which is defined as the difference between MAP and ICP (or central venous pressure, if greater than ICP). In healthy individuals, CBF is nearly constant between MAPs of about 60 and 160 mm Hg, as depicted in Figure 218.1. Within this range, increases or decreases in CPP result in vasoconstriction or dilation, respectively. Beyond these limits, however, blood flow becomes pressure dependent.

Unfortunately, the elegance of autoregulation can be lost or altered in several circumstances, resulting in great variation between individuals. The most common

example is in patients with chronic hypertension. In this population, the autoregulation curve is shifted to the right. That is, the threshold for pressure-dependent flow occurs at a higher MAP. Under other pathologic states, autoregulation can be impaired or even absent. Some of these conditions include ischemia, intracranial masses, traumatic brain injury, and subarachnoid hemorrhage. All of these scenarios ultimately place the patient at risk for inadequate CBF.

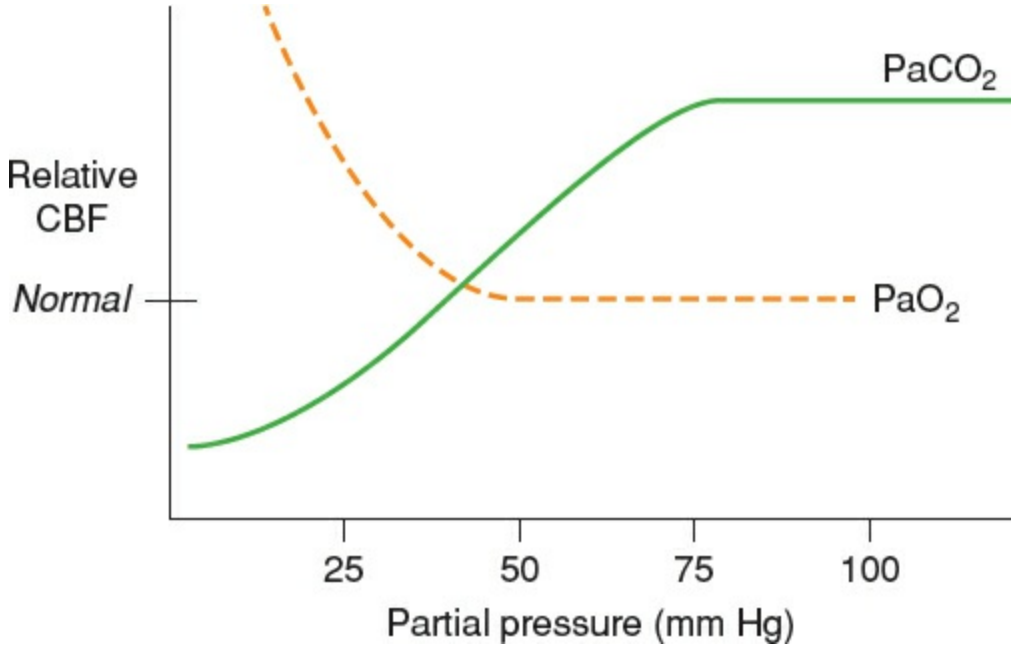


FIGURE 218.2. Respiratory gas tensions versus CBF. (Reprinted with permission from Marini JJ, Dries DJ. Critical Care Medicine: The Essentials and More. 5th ed. Philadelphia, PA: Wolters Kluwer; 2019.)

) **Respiratory gas tension—$PaCO_2$:** CBF is profoundly affected by and directly proportional to $PaCO_2$, a relationship that is greatest between $PaCO_2$ of 20 and 80 mm Hg (Figure 218.2). In fact, CBF changes rapidly by 1 to 2 mL/100 g/min for every 1 mm Hg change in $PaCO_2$. The mechanism behind $CO_2$ cerebral vasoreactivity is thought to be secondary to changes in the pH of CSF and cerebral tissue. Importantly, at $PaCO_2$ levels of less than 20 mm Hg, cerebral ischemia may occur due to both reductions in CBF, and to a left shift in the oxygen–hemoglobin dissociation curve. While manipulation of $CO_2$ is useful in managing patients with elevated ICP in the acute setting, the effect is temporary. After 6 to 8 hours, CBF returns to normal as CSF pH normalizes due to adjustments in bicarbonate levels. Hyperventilation should thus be considered a temporizing therapy in preparation for more definitive treatment such as decompressive craniectomy or barbiturate coma. Lastly, it is important to note that acute normalization of hyper- or hypocapnia may result in cerebral ischemia or increased ICP, respectively.

- **Respiratory gas tension—$PaO_2$:** Under normal circumstances, arterial oxygenation has little to no influence on CBF. However, under hypoxic conditions ($PaO_2$ <60 mm Hg), CBF rapidly increases to maintain oxygen delivery to the brain (Figure 218.2). This response is synergistic with the increased CBF that occurs during hypercapnia. At high $PaO_2$ values (greater than 300 mm Hg), only slight CBF decreases are seen.
- **Temperature:** Changes in temperature produce corresponding changes to CMR, resulting in changes in CBF. For every degree Celsius of temperature reduction, CMR decreases by 6% to 7%, with a resultant decrease in CBF. At 18° to 20°C, complete suppression of the EEG is seen. Interestingly, further temperature decreases (beyond those required for EEG suppression) continue to reduce CMR throughout the brain. Not surprisingly, hyperthermia (between 37° and 42°C) has the opposite effect on CBF and CMR, and should be avoided in patients with intracranial hypertension.
- **Blood viscosity:** Hematocrit is the most important determinant for blood viscosity. Like arterial oxygen tension, a hematocrit within the normal physiologic range only modestly influences CBF. However, beyond this range, a decrease in hematocrit reduces viscosity and improves blood flow. Of course, hematocrit reductions also decrease oxygen carrying capacity, and can induce increases in CBF in order to maintain a constant oxygen delivery to brain tissue. A markedly elevated hematocrit, as seen in polycythemia vera, will have the opposite effect on viscosity and result in decreased CBF. Thus, optimal viscosity is a delicate balance between adequate blood flow and oxygen delivery. Some studies suggest this occurs at hematocrit values of approximately 30% to 34%.

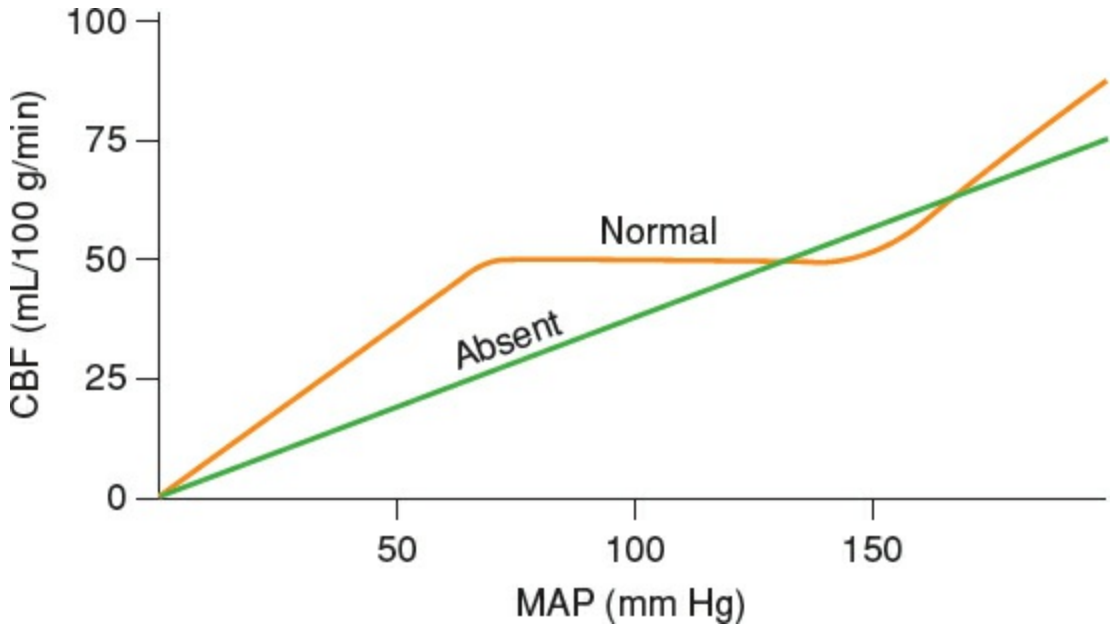


**FIGURE 218.3.** Impairment of cerebral autoregulation in the presence of volatile agents. (Reprinted with permission from Louis ED, Mayer SA, Rowland LP. Merritt's Neurology. 13th ed. Philadelphia, PA: Wolters Kluwer; 2015.)

Anesthetic Effects: Appreciating the above-described physiology helps us understand the effects of anesthetic agents. In general, modern volatile anesthetics reduce CMR by as much as 60% when burst suppression is achieved. However, volatile anesthetics are also direct cerebral vasodilators. These dual effects would seem to "uncouple" flow and metabolism when in fact they are two separate physiologic effects. Fortunately for our patient, CBF is not significantly affected until anesthetic concentrations surpass minimal alveolar concentration (MAC). At greater than 1 MAC, autoregulation is impaired, and direct vasodilation results in increased CBF despite a decrease in CMR (Figure 218.3). Interestingly, this effect can by offset by hyperventilation, as $CO_2$ vasoreactivity is maintained even in the presence of volatile agents.

Overall, intravenous agents reduce CMR and CBF, with the notable exception of ketamine, which significantly increases both parameters. Barbiturates, etomidate, and propofol, like volatile anesthetics, lower CMR by as much as 60% during burst suppression. In contrast to volatile agents, however, these intravenous agents are cerebral vasoconstrictors and therefore, CBF is also decreased. Opiates and benzodiazepines affect minor decreases in CBF and CMR.

## TAKE HOME POINTS

- An anesthesiologist must understand CBF physiology while caring for a patient with neuropathology.
- CBF varies directly with $PaCO_2$ and CMR.
- Cerebral autoregulation is altered by chronic hypertension and may be lost completely with intracranial pathology.
- Volatile agents depress CMR and increase CBF in a dose-dependent manner via direct vasodilation.
- In general, intravenous agents decrease CMR and CBF, with the notable exception being ketamine.

## Suggested Readings

Butterworth JF, ed. Chapter 26. Morgan and Mikhail's Clinical Anesthesiology. 5th ed. New York: McGraw-Hill Medical; 2013.

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# Cerebral Aneurysm Versus "Routine" Craniotomy—The Anesthetic Goals Are Not the Same

James DeMeester, MD and Brian T. Gierl, MD

A 56-year-old woman with a history of hypertension presents to the Emergency Department with a 3-day history of headache that she describes as the worst of her life. It began suddenly and has not relented over the past 3 days. How would you manage this patient?

Cerebral aneurysms typically arise in the circle of Willis at vascular bifurcation points where hemodynamic stress is maximal. Ninety percent of aneurysms occur in the anterior circulation, and only 10% occur in the basilar system. Although cerebral aneurysms, if large enough, can manifest with symptoms of neural compression—classically a cranial nerve III palsy associated with a posterior communicating (PComm) artery aneurysm—the greatest concern is the occurrence of rupture and subarachnoid hemorrhage (SAH).

Intracranial aneurysms (ICAs) are responsible for 75% to 80% of episodes of SAH, which has an incidence of 10–20/100,000, and is associated with high morbidity and mortality. One-third of patients will die from their initial bleed, with another third having severe disability or delayed death. Only the remaining third will have minimal morbidity and an acceptable outcome.

The prevalence of undiagnosed, asymptomatic aneurysms is estimated at 4%; however, surgical clipping only confers significant outcomes benefit when aneurysm size exceeds 7 to 10 mm. Anterior communicating and PComm artery aneurysms are more likely to rupture than those at other sites. Endovascular treatment with coils causes an aneurysm to naturally clot off, but there is a higher risk of aneurysm recurrence with coils than with surgical clipping. The decision to use coils versus clips to secure an aneurysm is typically a function of the ability to access the aneurysm from the artery, the ability to expose it surgically, and the shape of the aneurysm—berry aneurysms with

stalks are more receptive to coils while wide-necked aneurysms are treated with endovascular stents or surgical clips. Timing of surgical intervention becomes more critical after a hemorrhage because the initial 72 hours present a window for operative management, after which surgery is delayed 10 to 14 days until the risk of vasospasm has decreased. When surgery is indicated, the anesthesiologist must realize that anesthetic considerations for SAH and ICA are unique from those of routine craniotomy.

The primary concern of an anesthesiologist during surgery for aneurysm clipping is the prevention of rupture. ICA rupture while the skull is closed has a mortality exceeding 75%. The likelihood of rupture is based on aneurysm size, wall strength, history of prior rupture, and transmural pressure (TMP). TMP is calculated as

$$TMP = MAP - ICP$$

where MAP is mean arterial pressure (measured at the circle of Willis) and ICP is intracranial pressure. You probably noticed that TMP equals cerebral perfusion pressure (CPP), but the concept of TMP and its concern with aneurysmal wall stress is unique to aneurysms. The periods commonly associated with intraoperative rupture are at induction, durotomy, hematoma evacuation, and during dissection to the aneurysm. Rupture during dissection or at the time of aneurysm clipping, carries with it much lower risk of vasospasm and hence reduced morbidity. Anesthetic priorities after a rupture are to maintain CPP. Controlled hypotension in an attempt to reduce bleeding is detrimental **but may be necessary under emergent conditions (e.g., aneurysmal rupture) to enable the neurosurgeon to clip the feeding vessel or aneurysm itself.**

Patients who have experienced an SAH may have regional ischemia and dysfunctional cerebral blood flow (CBF) autoregulation. Accumulation of extravascular blood increases ICP close to MAP, diminishing the perfusion gradient. Extravasated blood also contributes to localized vasospasm and furthers the risk of ischemia and a full-fledged stroke! Vasospasm is rare in the first 3 days following a bleed. Risk peaks around day 7 and generally resolves around days 10 to 14. These patients are typically in an ICU for 10 or more days post bleed with ICU nurses checking their neurologic status and recording their NIH Stroke Scale (NIHSS) every 1 to 4 hours. Clues to the presence of vasospasm, especially preoperatively, might include changes in mentation or new neurologic deficits. Newly evolving hemiplegia may indicate involvement of the middle cerebral artery, while hemodynamic and respiratory changes may suggest involvement of the posterior circulation. You've taken older individuals with blood in their head and subjected them to frequent neuro checks… it is no wonder that they will suffer from ICU delirium and exhibit changes in their NIHSS! The diagnosis of vasospasm is also made, more accurately, with angiography and transcranial Doppler. Vasospasm has been seen angiographically in 70% to 90% of patients with SAH;

intraoperatively we rely on neuromonitoring to diagnose it.

The classic preventative and therapeutic interventions for vasospasm were hemodilution, hypertension, and hypervolemia, referred to as "triple H" therapy or HHH. The idea was to augment CBF past strictures by increasing both cardiac output (hypervolemia) and CPP (hypertension) while reducing viscosity (hemodilution). While traditional HHH has fallen out of favor, the underlying principles still hold true. These patients often have poorly controlled hypertension that results in hypovolemia. In the setting of SAH, resuscitate to normovolemia. After the aneurysm is secured, MAP is typically capped at 200 mm Hg and if the patient displays symptoms at a low to normal blood pressure, vasopressors are added. Patients with SAH can suffer neurogenic cardiomyopathy as well. Intraoperative targets should include a normal MAP prior to aneurysm clipping, and a high-normal MAP after both temporary and definitive clipping.

Anesthetic induction should be free from acute increases in blood pressure while preserving CPP. An awake arterial line and an induction with adjunct agents, such as lidocaine, beta blockade, and narcotic, facilitate a smooth induction. A modification from our management of routine craniotomy is the avoidance of aggressive hyperventilation and hypocapnia at induction. This prevents precipitous decreases in ICP that would further increase the TMP gradient and the risk for rupture.

Once induction is complete, further positioning occurs with head pinning, and neuromonitoring leads are placed for evoked potentials or electroencephalography. These carry the risk of acute hypertension, and require aggressive blood pressure control and a stable plane of anesthesia. The anesthetic goals during the maintenance period of anesthesia are similar to that of routine craniotomy in that cerebral relaxation is desired. Gentle hyperventilation with the addition of osmotic diuresis facilitates a slack brain, facilitating surgical dissection. The technique of controlled hypotension during dissection of the aneurysm has been largely supplanted by the use of temporary clips. This lessens the risk of aneurysm rupture or rebleeding during the dissection phase. MAP should be increased after the clip is deployed to enhance collateral perfusion. An isoelectric EEG may be requested during this time, and is achieved by bolus and infusion of propofol. The IHAST Trial did not demonstrate a benefit to the use of mild hypothermia to reduce cerebral oxygen requirements during aneurysm clipping. A secondary analysis of that data also failed to show a benefit from a thiopental or propofol bolus to achieve an isoelectric EEG.

The goals for anesthesia wake up are to have a comfortable patient free from straining, coughing, and hemodynamic lability. Birds of a feather flock together, so be aware of the presence of other unruptured aneurysms as well! **Patients who are status post SAH and at risk for vasospasm should be intravascularly replete with a normal**

**to high-normal mean arterial blood pressure.** If surgery was indicated for SAH, then patients who are Hunt–Hess grades I and II should be able to be extubated, facilitating a prompt neurologic examination. Patients who are Hunt–Hess grades III and IV are usually left intubated. Realize that a postoperative angiogram is usually performed to evaluate whether an aneurysm remnant is still present that might rerupture.

## TAKE HOME POINTS

- Anesthetic considerations for surgery for SAH and ICA are unique from those of routine craniotomy.
- The overriding concern is to avoid rupture or rerupture of the aneurysm because ICA rupture with a closed skull carries a mortality rate exceeding 70%!
- Avoid aggressive hyperventilation and hypocapnia at induction.
- Controlled hypotension during routine dissection of the aneurysm has been largely replaced by the use of temporary clips, but be prepared for controlled hypotension in the case of emergent clipping of an acutely ruptured aneurysm.
- Extubation after aneurysm surgery generally depends on the preoperative Hunt–Hess grade—patients who are grade I or II are generally extubated, whereas patients who are grade III or IV usually have a course of postoperative intubation.

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# Perioperative Visual Loss Is One of the Most Feared and Devastating Complications of Spine Surgery

Ajay Sampat, MD and Laurel E. Moore, MD

It is the first day of your neuroanesthesia rotation and you're all set to start a major spinal reconstruction. You're assessing your patient in the preoperative area when the patient's spouse, a malpractice attorney, tells you that she's recently read about blindness after certain types of surgery and wants to know if you think there is a risk with this operation, and what you are going to do to prevent blindness?

Perioperative visual loss (POVL) is a rare but devastating complication of surgery that often has no proven treatment and is often associated with poor recovery. Fortunately the incidence of this complication in nonocular surgeries is low, ranging from 0.03% to 1.3%, with the highest incidence occurring during spinal and cardiac surgeries. More recently, POVL is a recognized complication of robotic surgeries as well. The timing of presentation of visual changes is variable, ranging from immediately postsurgery to up to 4 days postoperatively. Likewise, the deficit has a wide range of presentations, varying from a loss of a small portion of a visual to complete loss of light perception. Although the mechanisms of POVL are poorly understood, they may be broadly categorized into two general subgroups: ischemic optic neuropathy (ION) and central retinal artery occlusion (CRAO).

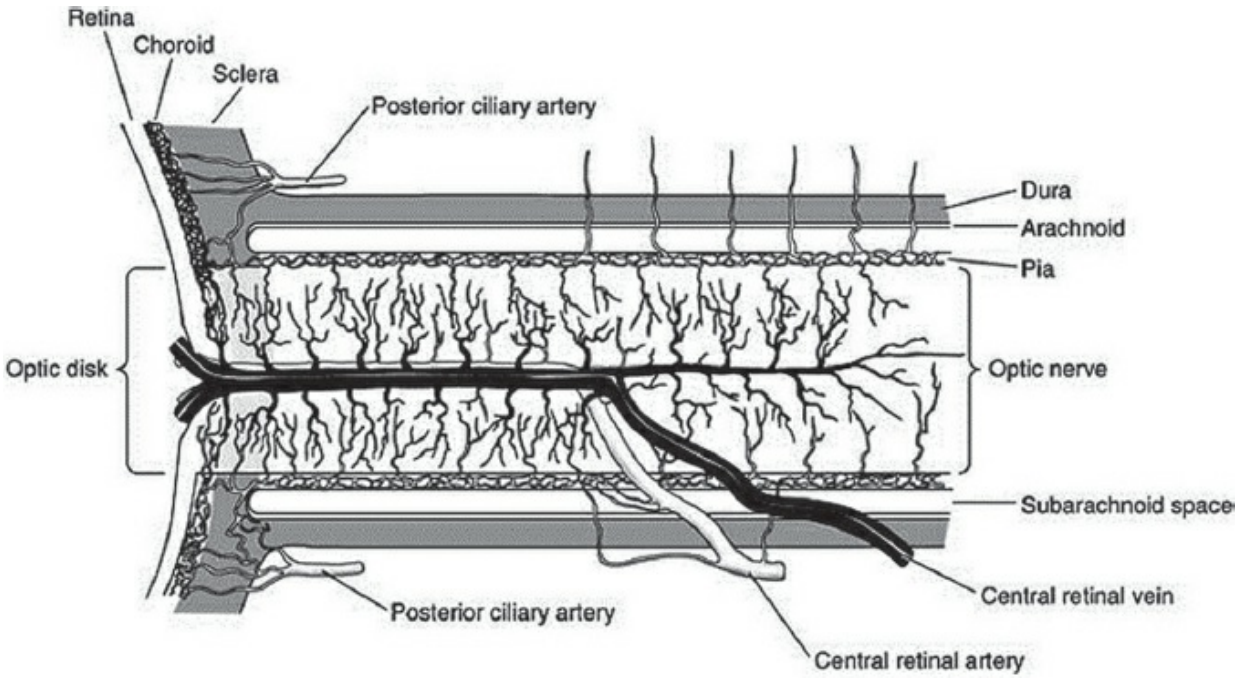


**Figure 220.1.** Blood supply of the optic nerve. (Reprinted from Hayreh SS. Anatomy and physiology of the optic nerve head. Trans Am Acad Ophthalmol Otolaryngol. 1974;78(2):OP240–OP254. Copyright © 1974 Elsevier. With permission.)

ION is the etiology most associated with POVL, accounting for more than 80% of POVL cases. Broadly speaking, it is the result of any process that leads to inadequate oxygen delivery to the optic nerve, including vascular vasoconstriction and decreased cardiac output, and its pathology is isolated to the optic nerve. In order to understand POVL, especially ION, it is important to have a basic understanding of the blood supply to the optic nerve (Fig. 220.1). The ophthalmic artery, which originates from the internal carotid artery, is the principal blood supply to the retina, globe, and optic nerve. The central retinal artery (CRA), a branch of the ophthalmic artery, supplies the inner retina. The anterior portion of the optic nerve has a rich arterial supply primarily from the posterior ciliary artery (PCA), while the posterior portion is supplied by the pial vascular plexus. In contrast to these densely supplied portions of the nerve, the central portion within the optic canal is supplied only by the pial vascular plexus derived from arterial extensions of the anterior and posterior blood supplies of the CRA. This comparatively sparse vascular supply to the mid portion of the optic nerve renders it more susceptible to ischemia, which is thought to be the anatomical mechanism responsible specifically for posterior ischemic optic neuropathy (PION), the type of ION that is most commonly associated with spine surgeries in the prone position.

With anterior ION (AION) the funduscopic examination is generally abnormal at presentation, distinguished by diffuse or segmental disc edema with ensuing atrophy (Fig. 220.2). In contrast, the funduscopic examination with PION is normal at presentation (Fig. 220.3) and then becomes abnormal over several weeks as the optic

nerve dies. PION tends to cause bilateral visual loss and is usually discovered at emergence from anesthesia. While the mechanism of ION is poorly understood, a recent multicenter case-control study has identified several patient risk factors for ION following prone spine surgery: male sex, obesity, use of the Wilson frame, prolonged anesthetic duration, greater estimated blood loss, and a lower percentage of colloid used in the nonblood replacement. The leading pathophysiologic mechanism for ION focuses on elevated venous pressure in the head, leading to interstitial edema that injures the optic nerve via direct mechanical compression, venous infarction, or compression of the vessels that feed the optic nerve. In addition, patients with pre-existing vascular comorbidities, such as systemic hypertension and diabetes, may be at higher risk for ION.

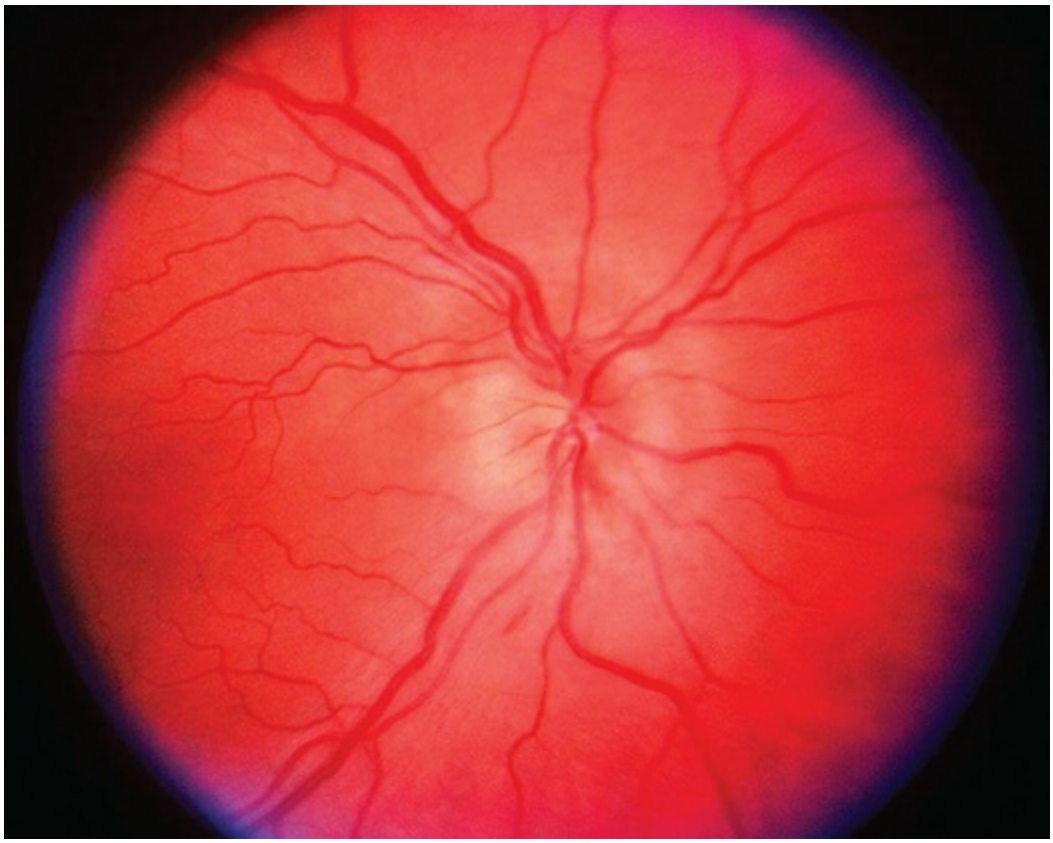

**Figure 220.2.** Funduscopic examination of acute anterior ischemic optic neuropathy demonstrating blurring of the optic disk margin from edema. (Image reproduced with permission from Medscape Drugs & Diseases (https://emedicine.medscape.com/), Anterior Ischemic Optic Neuropathy (AION), 2017, available at: https://emedicine.medscape.com/article/1216891-overview.)

The second most common cause of POVL, CRAO, accounts for roughly 10% of cases, and is associated with procedures in which large emboli may be injected near facial vessels or in which there is direct globe compression while in the prone position ("head rest syndrome") producing a decrease in retinal perfusion pressure. It is considered an ophthalmic emergency and is analogous to an acute stroke of the eye.

Signs and symptoms of CRAO include unilateral loss of vision, lack of light perception, an afferent pupillary defect, and edema formation of the periorbital area. Funduscopic examination classically reveals a cherry-red spot. Unlike ION, where up to 40% of patients have some return of vision, the prognosis for recovery from CRAO is poor, with approximately 60% of patients suffering permanent blindness and less than 25% recovering useful vision.

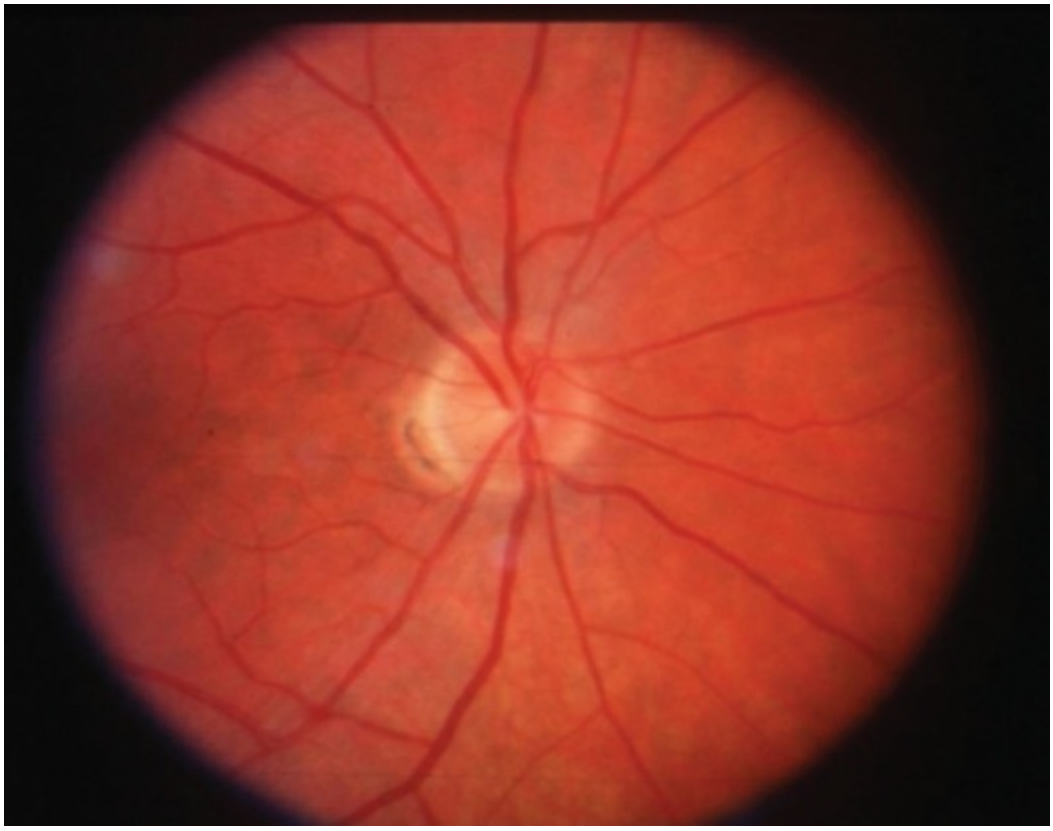

**Figure 220.3.** Funduscopic examination of a normal fundus and early posterior ischemic optic neuropathy. (Republished with permission of Dove Medical Press Ltd., from Berg KT, Harrison AR, Lee MS. Perioperative visual loss in ocular and nonocular surgery. Clinical Ophthalmol. 2010;4:531–546; permission conveyed through Copyright Clearance Center, Inc.)

Because of the devastating nature of POVL, the American Society of Anesthesiologists (ASA) released an updated advisory in 2012 from the ASA Task Force on Perioperative Visual Loss based on findings from the largest multicenter case-control study to date examining potential risk factors. It includes the following recommendations:

** Identify patients at high risk for POVL based on pre-existing comorbidities, expected prolonged surgical duration, and/or substantial blood loss and consider informing these patients that there is a low, but unpredictable risk of POVL.

** Systemic blood pressure should be continuously monitored (arterial line) in high-risk patients. Although deliberate hypotensive techniques (understood as being roughly 25% below baseline MAP) have not been shown to be associated with the development of POVL, its use should be carefully considered, particularly in patients with chronic hypertension.

** A combination of crystalloids and colloids should be used to maintain euvolemia. Central venous pressure monitoring should be considered in high-risk patients.

** Hemoglobin should be monitored periodically, particularly in high-risk patients and in cases with substantial blood loss. The Task Force did not have a specific lower hemoglobin limit at which the risk of POVL increases. However, it is the authors' belief that hemoglobin goal should be approximately 9 g/dL for major spine surgery in adults.

** Although subspecialty neuroanesthesiologists believed that the prolonged use of alpha-agonists could contribute to POVL, the Task Force believed that there was insufficient evidence to make a statement regarding the use of alpha-agonists.

** Avoid direct pressure on the eye to prevent CRAO. The high-risk patient's head should be maintained in a neutral position with the head higher than the heart whenever possible.

** For complex spine surgery, consideration should be given to the use of staged procedures in high-risk patients.

** Postoperatively, a high-risk patient's vision should be assessed as soon as a patient becomes alert (e.g., in the recovery room, ICU, or nursing floor). When POVL is suspected, immediate ophthalmologic consultation should be obtained. Additional management may include optimizing hemoglobin values, hemodynamic status, and oxygenation.

Unfortunately, once POVL is recognized postoperatively there are few treatment options. For suspected CRAO, potential therapeutic interventions aimed at lowering intraocular pressure include ocular massage and administration of acetazolamide or osmotic diuretic agents. Other potential therapeutic maneuvers include induced hypercarbia, topical hypothermia, or locally applied thrombolytic agents, although these

maneuvers are of questionable benefit. For both CRAO and ION, optimization of hemoglobin, MAP, and oxygenation are probably of greatest benefit. Magnetic resonance imaging (MRI) should be considered to rule out other possible causes of postoperative blindness, including pituitary apoplexy, posterior reversible encephalopathy syndrome, or cortical blindness. In any case, immediate ophthalmic evaluation is warranted if the diagnosis of POVL is being considered.

## TAKE HOME POINTS

- POVL is most common after cardiac and prone spinal fusion cases, with an incidence rate of 0.03% to 0.1% in spine surgeries.
- Specific risk factors for ION associated with prone spinal fusion surgery include male sex, obesity, use of Wilson frame, prolonged anesthetic duration, greater estimated blood loss, and a low percentage of colloid in the nonblood replacement.
- Risk modification strategies are aimed at minimizing the operative duration, estimated blood loss, and venous congestion and interstitial edema formation in the head. Surgeons should also consider staging procedures in high-risk patients.
- Optimization of mean arterial pressure and hemoglobin with careful presurgical patient positioning are probably the best ways to minimize the risk of POVL. Positioning goals should include reducing venous pressure by elevating the head (retina) above the heart and confirming throughout surgery that the orbit is free of pressure from any source.
- POVL should be discussed preoperatively with patients considered to be at high risk.

## Suggested Readings


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# Being Maximally Prepared for Minimally Invasive Pituitary Surgery

Rashad Albeiruti, MD

As you preview case assignments for tomorrow, you might mistakenly dismiss your scheduled transsphenoidal pituitary surgery as a simple procedure—something minimally invasive with an otolaryngologist. However, beneath a seemingly uncomplicated procedure lies the potential for significant perioperative complications. As such, it is in your best interest to treat these surgeries with the utmost preparation.

Minimally invasive transsphenoidal pituitary surgery, most often via an endoscopic transnasal approach, is an increasingly common procedure. In fact, pituitary gland tumors account for up to 10% of intracranial tumors and 20% of all intracranial operations. At the outset, the anesthesiologist should know the nature of the pituitary lesion such as size, whether there is mass effect, which hormones are implicated, and if it is secreting anything: growth hormone (GH), adrenocorticotropic hormone (ACTH), follicle-stimulating hormone (FSH), luteinizing hormone (LH), prolactin, and thyroid-stimulating hormone (TSH). The challenge for us in formulating an appropriate anesthetic plan is being able to appropriately address the clinical manifestations of a malfunctioning pituitary gland in conjunction with the various co-morbidities with which these surgical patients present, all of which have a direct impact on airway, breathing, and circulation. Understanding the pathophysiology of the pituitary disease process will ultimately help one prevent, prepare for, anticipate, or appropriately deal with complications that may arise before, during, and after surgery.

Anesthesiologists pride themselves on being airway experts, and this patient population has the potential to test our expertise. For example, patients with acromegaly due to the hypersecretion of GH may exhibit hypertrophy of various facial and airway tissues, such as the mandible, tongue, and oropharynx, which can render an airway challenging. Along with Cushing's disease (excess glucocorticoids) patients, those with acromegaly are often obese and suffer from OSA, complicating airway management at induction and emergence. In addition, a variety of pituitary gland disorders may have an

associated thyroid goiter which can compress the airway. Thus, **preoperative airway assessment is crucial.** Being prepared for a difficult airway is of chief importance. Finally, noninvasive positive pressure ventilation is contraindicated, as it results in both pneumocephalus and meningitis, so perioperative administration of opioids and benzodiazepines must be dosed with caution.

Many patients with pituitary disorders have underlying cardiovascular disease. In fact, cardiac disease is the most common cause of morbidity and mortality in acromegaly patients. These patients often have hypertension, CAD, and diastolic dysfunction as they build cardiac muscle just as they build skeletal muscle. In Cushing's patients, hypertension is common secondary to excess glucocorticoids. The surgeon often injects epinephrine to limit blood loss from the intranasal submucosa. This practice has the potential to trigger dysrhythmias and hypertension, thereby exacerbating pre-existing cardiac conditions. It is therefore important to thoroughly examine a patient's cardiac record prior to surgery, to closely monitor the patient in the perioperative period and of course be prepared to treat problems.

Bleeding is a dreadful complication for both the anesthesiologists and surgeons. The most feared, albeit rare, hemorrhagic complication can arise from accidental injury to the intracavernous internal carotid artery (Fig. 221.1). Risk factors for such bleeding include cavernous sinus invasion or adhesion to the ICA by the tumor, scar tissue resulting from previous transsphenoidal surgery, and radiation therapy. One must **always be prepared for further invasive line placement, both for resuscitation and monitoring**, should unexpected bleeding occur. In addition, accidental invasion of the cavernous sinus may necessitate further interventional procedures. The surgeons may perform a Balloon Test Occlusion in interventional radiology in order to determine the impact of sacrificing the ICA on the patient's cognitive status—a stroke test, if you will. Surgeons may request deliberate hypotension throughout the case in order to purportedly minimize bleeding and improve visualization. However, a patient's cardiovascular history must be taken into consideration before hastily accommodating such requests, especially given that these patients are usually in a head-up position; you, the anesthesia provider will rely on neuromonitoring to identify a stroke. Generally, a mean arterial pressure of less than 65 mm Hg is not advised. Total intravenous anesthesia (TIVA) may also be beneficial in terms of surgical visualization, in theory producing less vasodilation and surgical bleeding than a volatile-based anesthetic. Subjective improvement in surgical field conditions with TIVA has been shown for FESS but not specifically for transsphenoidal hypophysectomy. And while properly titrated propofol and remifentanil can bring about patient immobility, paralytics may also be utilized (provided the surgeon is not monitoring EMG), as any movement can be disastrous, causing further vascular injury or CSF leak.

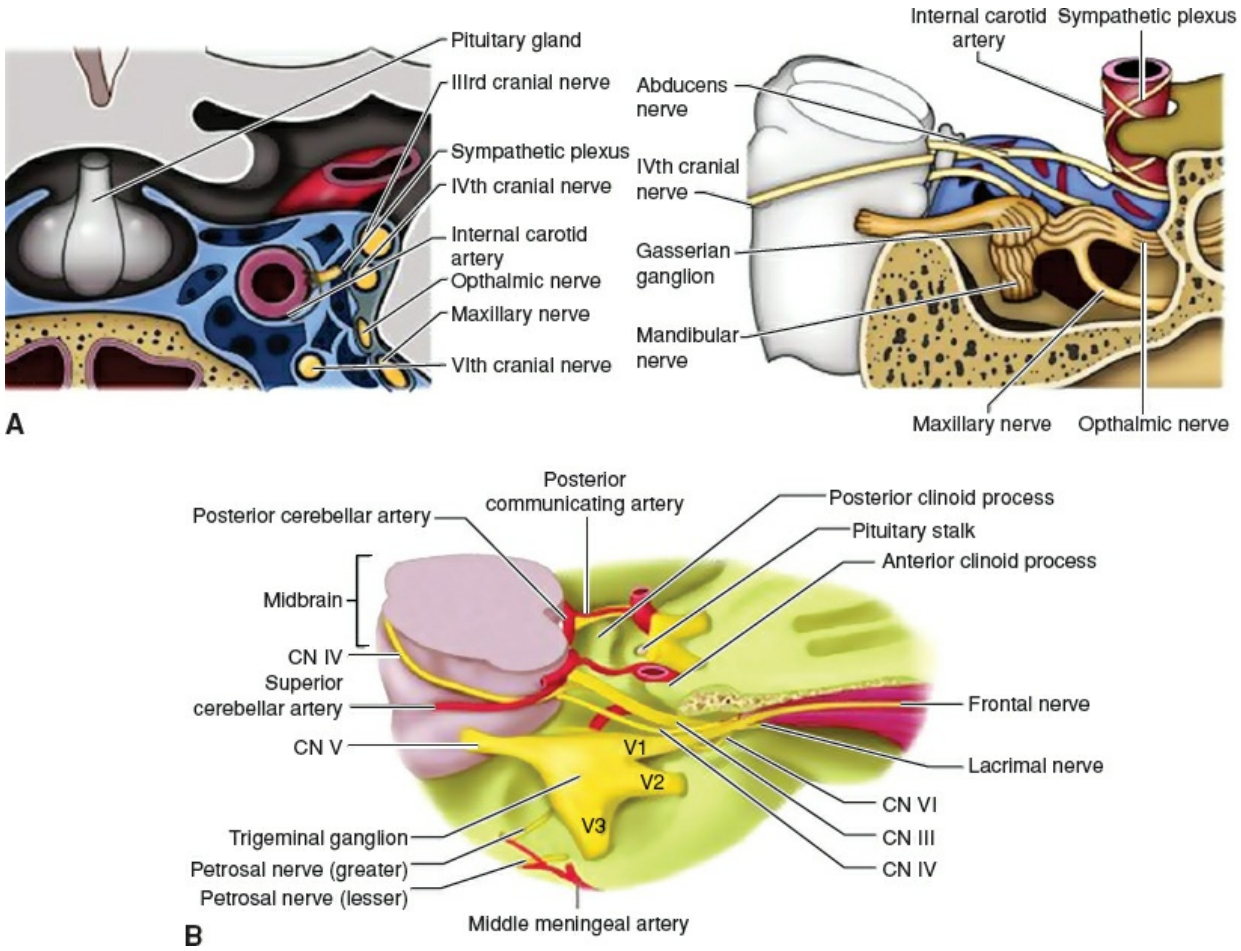


**Figure 221.1.** Anatomical diagram of anatomy relevant to transsphenoidal surgery. **A.** This coronal view of the cavernous sinus demonstrates the anatomical relationship of the pituitary gland with various surrounding structures, such as the intracavernous internal carotid artery. **B.** An oblique view of relevant skull base anatomy. (From Mancuso AA, Hanafee WN, Verbist BM, et al. Head and Neck Radiology. Philadelphia, PA: Wolters Kluwer, Lippincott Williams & Wilkins; 2011.)

It can be difficult to conduct a continual fluid balance in the OR when the EBL is >1 L and the urine output is ~1 L/hr. Intraoperative diabetes insipidus (DI) is a common pathology of water balance. Syndrome of Inappropriate Antidiuretic Hormone Secretion (SIADH) is also commonly encountered (Table 221.1). A transient form of DI can occur during surgery, or it may develop 1 or 2 days after pituitary surgery; either are usually transient and self-limiting. It is simply diagnosed by increased urine output, sodium level, and plasma osmolality along with decreased urine osmolality. Treatment can involve using a synthetic analog of ADH, such as DDAVP, but beware that overzealous DDAVP administration can lead to hyponatremia. SIADH presents with hyponatremia, hypoosmolar serum with hyperosmolar urine, and a euvolemic state. One must be able to differentiate this hyponatremia from that caused by cerebral salt wasting (CSW) syndrome. SIADH treatment ranges from fluid restriction to hypertonic saline; but know your diagnosis: fluid restriction during CSW can lead to a state of hypovolemic shock. Hypertonic saline is used if sodium is less than 120 to 125 in combination with

neurologic symptoms such as seizures or coma. In both the assessment and treatment process of these water balance complications, one should monitor sodium so as to avoid unnecessary pharmacologic treatment and over-correction, respectively.

**Table 221.1 ■ Comparison Between Diabetes Insipidus (DI) and Syndrome of Inappropriate Antidiuretic Hormone (SIADH)**

| | DI | SIADH |
|---|---|---|
| Signs and symptoms | Polyuria (4–20 L/day) and polydipsia | Euvolemia and hyponatremia |
| Diagnosis | Serum: >300 mOsm/L<br>Urine: <150 mOsm/L<br>Serum Na: >145 mEq/L | Serum: <270 mOsm/L<br>Urine: >100 mOsm/L<br>Serum Na: <135 mOsm/L |
| Treatment | • Replace $H_2O$ deficit<br>• DDAVP | • Fluid restriction<br>• Hypertonic saline (if neurologic symptoms) |

## TAKE HOME POINTS

- Preoperative airway, cardiovascular, neurologic, and endocrine assessment is important, both to establish a baseline and to help prevent and treat potential complications. There is a high incidence of cardiac comorbidity in this patient cohort.
- Have a high suspicion for a difficult airway and be prepared! These patients also often have sleep apnea.
- Bleeding is a rare but potentially catastrophic complication of transsphenoidal pituitary surgery. Violation of the intracranial carotid artery is a truly dreadful event, but it does happen. Always be prepared to secure extra intravenous access and invasive monitoring.
- We do not advise a MAP of less than 65 mm Hg, no matter what the surgeons request.
- Postoperative endocrine complications, especially that of water balance, are common.

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# Evoked Potentials: Don't Approach the Surgeon or Neurophysiologist Until You Know These Principles

Anthony N. Passannante, MD and Laurel E. Moore, MD

Perioperative nerve injury can occur with any procedure and can have considerable consequences. Ideally the patient would be able to demonstrate nerve function, but when that is not possible, intraoperative neurophysiologic monitoring is used to detect neurologic compromise—hopefully before the damage becomes irreversible. There are numerous intraoperative monitoring modality substitutes for an interactive patient, including somatosensory-evoked potentials (SSEPs), motor-evoked potentials (MEPs), brainstem auditory-evoked potentials (BAEPs), and visual-evoked potentials (VEPs). Their selection is based on the area at risk for injury, the ability to alter the procedure to compensate for the injury, and the risks involved with monitoring modality. Monitoring evoked potentials (EPs) can be challenging for the anesthesia provider because many of the anesthetic agents currently used affect signal quality, and motor stimulation can also result in patient movement that may add risk to the procedure. The anesthesia provider must communicate with the surgeon and neurophysiologist prior to surgery regarding what EPs will be monitored in order to decide on an anesthetic plan that will optimize this monitoring.

EPs are measurements of the electrical potentials produced when the nervous system is stimulated in contrast to the electroencephalogram (EEG), which records spontaneous electrical activity generated by the central nervous system. EPs may be generated by sensory, magnetic, electrical, or cognitive stimulation. They are characterized by both latency and amplitude. The latency of an EP is the time between a stimulus and the occurrence of the EP. The amplitude is the magnitude of the EP. EPs can be monitored noninvasively from electrode stickers on the skin or invasively by monitors placed within the surgery field. If patient pathology (including obesity and neuropathies) reduces EP signals, needles may replace electrode stickers and can result in blood exposure. A needle stick always makes for a bad day in the OR.

To obtain SSEPs, a peripheral sensory nerve is repetitively stimulated (e.g., median

nerve or posterior tibial nerve) and the response is recorded with electrodes placed over the primary sensory cortex. The signals are filtered and averaged for interpretation. SSEPs monitor the well-being of the dorsal column functions (position, vibratory sense, and light touch) as well as portions of the brainstem and cerebral cortex. Specifically, the pathway includes the peripheral sensory nerves (cell bodies in the dorsal root ganglia) → which ascend via the ipsilateral dorsal column to synapse in the medulla → secondary fibers decussate and ascend to the contralateral thalamus → tertiary fibers ascend from the thalamus to the primary sensory cortex (postcentral gyrus). Note that SSEPs provide little or no information on the anterior columns (read: motor function), and there are reports of patients with normal intraoperative SSEPs who awaken with new motor deficits. Fortunately, this is rare despite the dorsal columns having a different blood supply (posterior spinal arteries) than the anterior columns (anterior spinal artery). However, it is theoretically possible to have hypoperfusion to the anterior columns (e.g., during a thoracic aortic aneurysm repair) that SSEPs may fail to recognize. SSEPs are monitored during aneurysm surgery (median nerve during middle cerebral artery aneurysms, posterior tibial nerve during anterior circulation aneurysms—remember your homunculus!), brain tumors including the posterior fossa, and many spine surgeries.

MEPs entail applying a current directly or transcranially to the primary motor cortex (precentral gyrus) or spinal cord to initiate an action potential. The action potential then descends from the motor cortex through the pyramidal decussation to the contralateral lateral corticospinal tract. These neurons then synapse on the ventral horn with an alpha motor neuron that travels to the muscle. MEPs can be measured at numerous points along this pathway. Neurogenic MEPs are responses recorded in the periphery following stimulation of the spinal cord. Myogenic MEPs are EPs recorded over the muscle belly as compound muscle action potentials (CMAPs). Some spine surgeons choose to monitor the anterior columns with MEPs in addition to the dorsal columns via SSEPs. There is a major publication by Thirumala et al., regarding the utility of MEPs. It argues that MEPs can be difficult to obtain and maintain, so that many patients have significant MEP signals intraoperatively but awaken without deficits without an intervention having been performed. MEPs have a downside—they limit the anesthetic technique to TIVA, cause the patient to twitch so that the field may not be akinetic, and may cause masseter contraction with tongue trauma or damage to the ETT. However some institutions monitor MEPs for all of their spine surgeries.

BAEPs and VEPs are two additional forms of EPs that may be monitored intraoperatively. BAEPs record subcortical responses from auditory stimuli and monitor the entire auditory pathway, including brainstem nuclei. These prove useful in surgeries near the cerebellopontine angle and particularly help with auditory

preservation during resection of acoustic neuromas. VEPs record cortical responses from visual stimuli and monitor the visual pathway. This form of EPs is useful in surgeries near this pathway (i.e., parasellar region). Unlike BAEPs, VEPs are exquisitely sensitive to anesthetic agents.

Because all anesthetic agents have effects on the central nervous system, the anesthetic management of patients undergoing neurophysiologic monitoring is vital. Synaptic transmission is more sensitive to anesthetic agents than mere axonal conduction. Therefore, pathways with multiple synapses (e.g., MEPs, VEPs) are more sensitive to anesthetic agents than those pathways with few (e.g., subcortical SSEPs or BAEPs). The typical effect of most anesthetic agents is to decrease the amplitude and increase the latency of EPs. Anesthetic agents with these effects include the halogenated inhalational agents, propofol, benzodiazepines, and barbiturates. Nitrous oxide has depressant effects on amplitude and minimal effects on latency. Conversely, ketamine and etomidate have minimal effects on EPs and may enhance SSEP amplitude. Opioids also have minimal effects on SSEPs and MEPs, making them a popular choice in EP monitoring. If you can't obtain signals at the start of the case, you might reduce or eliminate the volatile anesthetic or add ketamine. An intraoperative loss of signals that are independent of surgical manipulation/injury should be treated with an increase in perfusion with consideration to both perfusion pressure and cardiac output (Table 222.1).

**Table 222.1 ■ ■ Evoked Potential Modalities and Anesthetic Compatibility**

| Modality | Common Uses | Anesthetic Compatibility | | |
|---|---|---|---|---|
| | | Neuromuscular Blocking Drug | Volatile Anesthetic | Ketamine Impact |
| SSEP | Neurosurgery to monitor spinothalamic sensory strip tract and dorsal spinal cord | Yes, reduces myographic "noise" | Tolerated but dose dependent | Improves amplitude |
| EMG | Thyroidectomy—recurrent laryngeal nerve monitoring<br>Any dissection around a motor nerve—remember the chorda tympani<br>Spinal fusion and instrumentation—stimulating screws to determine proximity to nerve roots | No, but can tolerate low dose | Yes | Minimal impact |
| MEP | Neurosurgery to monitor motor strip—corticospinal tract and anterior spinal cord | None | None/low dose | Improves amplitude |
| BAEP | Craniotomy for tumors involving brainstem or CN VIII | Yes | Yes | None |
| VEP | Uncommon; limited by exquisite sensitivity to anesthetic agents and need for headgear to provide visual stimulation | Yes | No | Not well established, beware nystagmus |

Neuromuscular blockers produce a dose-dependent decrease in CMAP amplitude, thus affecting the MEP and electromyogram (EMG). They obviously do not have effect on sensation—otherwise we'd use them for intraoperative analgesia-–and therefore, do not interfere with SSEP transmission. On the contrary, they improve SSEP monitoring because it decreases electromyographic noise. Although neuromuscular blockade decreases the ability to monitor MEPs and EMGs, some degree of relaxation may be needed to help with surgical exposure and to prevent patient movement. Working with the neurophysiologist, a balance can be found to satisfy both the needs of the surgeon and the neurophysiologist. Care should be taken to pad extremities and pressure points, as well as to protect the tongue and oropharynx, to prevent injury during MEP stimulation in patients who are not fully relaxed.

Once the surgical procedure and type of neurologic monitoring are known, anesthetic management can be planned. The anesthetic should provide for hemodynamic stability and patient comfort, while permitting optimal conditions for neuromonitoring. This entails the use of a stable anesthetic and avoidance of medication boluses. If a change is noted in amplitude or latency, it is vital that there be no confusion as to whether the change is due to surgical manipulation or a change in anesthetic management.

Furthermore, in the event of a significant change in signals, the possibility of an intraoperative wake-up test should be considered when planning the anesthetic. Medications that are rapidly titrated, such as desflurane, nitrous oxide, short-acting opioids, and low-dose propofol, generally provide for good signals and a rapid wake up should this become necessary. For MEPs, particularly in myelopathic patients who have abnormal signals, consideration should be given to using propofol in combination with ketamine, although whether this is better than low-dose volatile agent is unclear. If there is a need to determine whether a loss of signals is real or artifact (e.g., needle displacement), a bolus of etomidate may accentuate poor signals provided that the hardware is in place.

A variety of nonsurgical factors such as temperature, hypotension, anemia, and even brain shrinkage (from cerebral spinal fluid drainage) can affect signals over time. When do these changes become significant? In general, a decrease in amplitude of ≥50%, or a ≥10% increase in latency, deserves investigation. Sudden or unilateral changes certainly suggest surgical trespass. More gradual or bilateral changes are suggestive of anesthetic or physiologic change. Regardless of the circumstances, when there is a significant change in signals, the anesthesia team should evaluate (a) whether MAP is adequate and consider increasing MAP 20% above baseline, (b) check hemoglobin and oxygen saturation to ensure adequate oxygen delivery, and (c) ensure that the anesthetic technique has remained stable.

Last, communication is a vital portion of successful EP monitoring. The anesthesiologist must communicate with the neurophysiologist and surgeon about changes in anesthetic management or physiologic parameters that may result in changes in signals. Likewise, the neurophysiologist must communicate with the anesthetic and surgical teams about any significant change in signals so they may respond appropriately.

## TAKE HOME POINTS

- EP monitoring is actually a "family" of intraoperative monitoring modalities used to decrease neurosurgical morbidity and detect neurologic compromise before the damage becomes irreversible.
- The anesthesia provider should expect to interface with the surgeon, the neurologist, and the EP technician concerning the specific technique to be used for a given case.
- Noninvasive monitoring on the extremities is usually done by placing pad electrodes on the skin, but **beware,** often needle electrodes are used on the scalp.
- SSEPs are the form of intraoperative neurophysiologic monitoring with the widest clinical application.
- The use of MEPs has increased as spine surgery has become more complex.

- The typical effect of most anesthetic agents is to decrease the amplitude and increase the latency of EPs. Anesthetic agents with the most pronounced effects include the halogenated inhalational agents, propofol, benzodiazepines, and barbiturates. Opioids have minimal effects on SSEPs and MEPs, making them a popular choice in EP monitoring cases.
- Always be ready to reevaluate your anesthetic if a significant change occurs in the EPs, and always be ready for a wake-up test.

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# Awake Craniotomy

Ravnita Sharma, MD FRCA and Laurel E. Moore, MD

Your patient is a 63-year-old man with a past medical history of metastatic melanoma who presents with word-finding difficulty and headache. On an MRI with contrast, the T1 images showed a small mass with associated edema and a pan-CT was without another primary source of tumor. His speech has improved with steroid treatment and he now presents for surgical resection.

## Introduction

Awake craniotomy is becoming increasingly popular for procedures including epilepsy surgery, surgery for movement disorders, and for resection of brain tumors encroaching on eloquent areas of the cerebral cortex (sensory, motor, and speech areas). The procedure allows real-time intraoperative assessment of the patient's neurologic function so that the surgeon can perform a more aggressive resection. The advantages of these procedures for lesion resections include increased lesion removal leading to improved survival and quality of life, a lower requirement for high-dependency care, shorter duration of hospital stay, and reduced costs; for movement disorders, the ability to immediately test lead placement is obviously invaluable.

The underlying anesthetic for any "awake craniotomy" is an effective scalp block, which is discussed below (see Figure 223.1). The balance of the anesthetic technique is typically performed with a patient receiving deep sedation ("awake–awake" technique) or a general anesthetic ("asleep–awake" technique) for the craniotomy, followed by an awake phase for testing during the procedure and the return of anesthesia (usually deep sedation) for closure. Videos of the awake portion can be seen on the Internet and recently include a man playing his guitar. Both the neurosurgeon and neuroanesthesiologist must be experienced in awake craniotomy procedures and a thorough preoperative assessment to ensure appropriate patient selection and detailed patient explanation are crucial for a smooth and successful intraoperative course. **When performed appropriately, an awake craniotomy is surprisingly well-tolerated by**

**patients.** We recommend that you consult with the rest of the surgical team before promising the patient that they can play their guitar in the operating room (OR)!

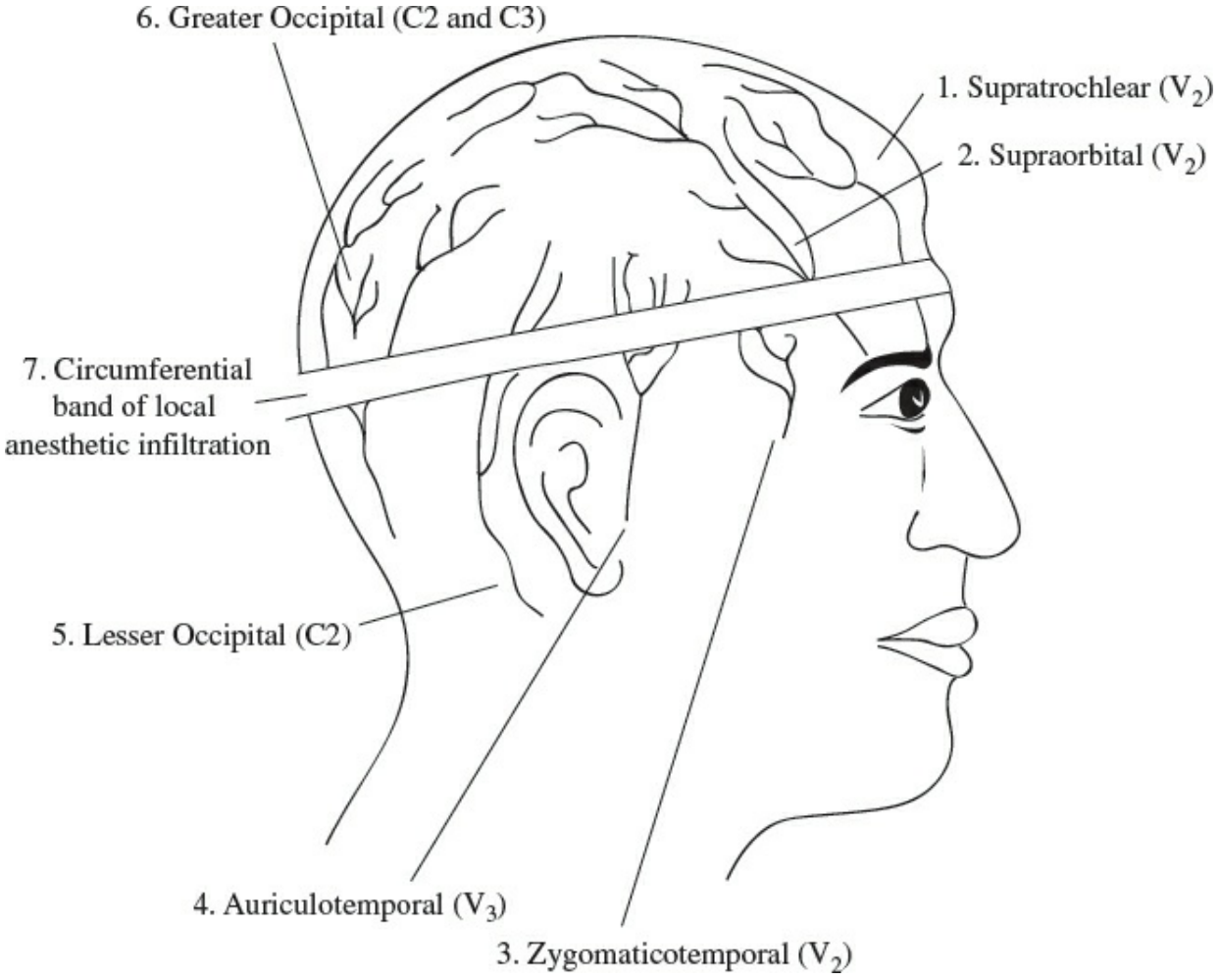


**Figure 223.1.** Schematic anterior and posterior view of the scalp.

In larger neurosurgical centers, a dedicated multidisciplinary team consisting of neurosurgeons, neuroanesthesiologist, neurologist, neuropsychologist, scrub nurse, and circulating nurse remains present with the patient in the OR and all should be involved in the preoperative consultation and preparation of the patient. **An awake patient whose head is in pins and has just had a craniectomy is not interested in meeting new people.**

## Preoperative Considerations

Careful preoperative assessment, appropriate patient selection, and detailed explanation are essential for success. Unlike most procedures, this patient will only receive analgesia and mild anxiolysis during their procedure, which involves probing and manipulating their brain! The anesthesiologist must perform a full assessment including

an airway examination, as some form of airway management may be required during the sedation phase, and he/she must also carefully consider the patients' comorbidities. Table 223.1 highlights patient screening factors that may cause problems intraoperatively if not managed appropriately.

Occasionally it may be helpful for the patient to visit the OR and visualize their environment before the day of surgery.

Maintaining a calm environment from the moment the patient arrives in the preoperative holding area is important and value is added in meeting the members of the awake craniotomy team in advance of the day of surgery. It can also be helpful to have music playing in the background, taking into consideration requested music type expressed by the patient. Acetaminophen is recommended to help with the mild headache from the fixator pins that may ensue during the wake-up phase of the procedure.

**Table 223.1 ■ Patient Screening Factors and Management Strategies**

| Patient Factors | Management Strategies |
|---|---|
| Severe anxiety or psychiatric illness | Preoperative counseling/rapport building |
| Claustrophobia | Careful surgical draping |
| Confusion or difficulty in communication | Relative contraindication |
| Young age | Parent/guardian/play therapist presence |
| Obesity | Weight reduction strategies |
| Sleep apnea | Nasal trumpet insertion (consider oxymetazoline)/carefully titrated sedation/tonsillectomy and defer surgery if possible |
| Gastroesophageal reflux disease/nausea | Ranitidine; ondansetron; reverse Trendelenburg positioning |
| Inability to lie supine and immobile | Pillows, padding, lateral positioning |
| Chronic pain | Consider opioid taper; multimodal analgesia, acetaminophen |
| Signs of moderate-to-severe | Relative contraindication (lack of |

| | |
|---|---|
| intracranial hypertension | controlled ventilation; herniation risk) |

Placement of venous and arterial access lines on the ipsilateral side allows easier and more comfortable access for the patient to the contralateral limbs during the phase of motor testing. As soon as the peripheral IV is placed, a small dose of opiate such as fentanyl together with an infusion of dexmedetomidine may be commenced to provide a degree of sedation and anxiolysis before the patient enters the OR. Table 223.2 summarizes the anesthesiologist's preoperative checklist for awake craniotomy procedures.

Finally, to ensure that a continued calm atmosphere prevails for the patient from arrival in the OR, it is vital that communication between the neurosurgeon and anesthetist is effective and it is recommended that all members of the awake craniotomy team undergo a prebriefing huddle. Topics to discuss at the huddle include the specific plan for dealing with a patient who becomes unexpectedly agitated during the procedure, or fire (there is an oxygen-enriched environment due to the oxygen delivery through nasal cannula and the electrocautery is the energy source), room temperature, noise level, focus of conversation during periods of light sedation, exact patient positioning and arrangement of drapes, tasks that will be requested of the patient during testing.

**Table 223.2 ■ Anesthesiologist Preoperative Checklist**

| Checklist | Circle Response |
|---|---|
| Fasting status confirmed | **Y/N** |
| Timing of last anti-seizure medication—hold AED for epileptiform mapping | **Y/N** |
| IV placement on ipsilateral limb | **Y/N** |
| Arterial line placement on ipsilateral limb | **Y/N** |
| Administer 1-g acetaminophen PO | **Y/N** |
| Type and screen | **Y/N** |

**Table 223.3 ■ Anesthetic Technique**

| Anesthetic Mode | Anesthetic Method | Anesthetic Airway | Primary Analgesia |
|---|---|---|---|
| Sedation only | Awake throughout | $O_2$ +/− nasal airway | Scalp block |
| General anesthetic | Asleep–awake followed by asleep | LMA asleep/LMA removed for awake phase | Scalp block |
| | | Endotracheal tube (ETT) asleep/ETT removed for awake phase | Scalp block |

## Intraoperative Management

There is no recognized consensus on the best anesthetic approach to an awake craniotomy (see Table 223.3). The choice of anesthetic mode and method is influenced by the experience of the anesthesiologist, duration of surgery, and patient factors. In certain circumstances such as severe patient anxiety, a laryngeal mask airway (LMA), which can be removed during the awake phase, may be suitable. Table 223.4 illustrates the advantages and disadvantages of using a supraglottic device such as an LMA. In any case, an LMA may readily be required for rapid airway control due to apnea during the awake phase or unexpected brain swelling (requiring hyperventilation to treat) and contingency plans for this are anticipated as part of the preoperative airway examination.

**In any case, the scalp block is the cornerstone of the anesthetic.** The timing of the scalp block is important, particularly in procedures where stealth-guided 3D techniques are used by the surgeons. In these cases, the scalp block must be delayed until the stealth guidance registration is complete. Otherwise the scalp deformity caused by the local anesthetic administration will reduce the accuracy of the stealth approach. As stealth technology is used in most centers that do awake craniotomy, the anesthetic for pin placement (which is also very painful) must be done by administering local anesthetic (typically 0.5% ropivacaine) at the exact site of intended pin placement. The person placing the local anesthetic has to deposit adequate amount of drug in both the skin and the periosteum of the skull, as these are the main sites for pain associated with pin placement. Once the navigation registration is complete, the scalp block is done to

anesthetize the supraorbital, auriculotemporal, and occipital nerves on the side ipsilateral to the intended surgery. As the scalp is very vascular, it is recommended that ropivacaine is used in preference to bupivacaine to prevent systemic toxicity and adding epinephrine (1:200,000) to prevent quick systemic absorption. A schematic anterior and posterior view of the scalp is shown at the end of the chapter.

The temperature of the OR should be warm and blankets may be applied to the patients' upper and lower body. Once the standard monitors have been applied and nasal cannula oxygen commenced, additional sedative agents may be introduced (e.g., low-dose propofol and remifentanil). A fine balance of sedation is required to achieve spontaneous ventilation. Avoidance of airway obstruction with maintenance of normocarbia and normal blood pressure is most desirable. A soft nasopharyngeal airway inserted into one of the nares after preparation of the nasal mucosa with topical vasoconstrictor will help to relieve a partially obstructed airway and can safely remain in situ throughout the procedure.

**Table 223.4 ■ Advantages and Disadvantages of LMA Use**

| Advantages of LMA Device Insertion | Disadvantages of LMA Device Insertion |
|---|---|
| Useful in cases of severe patient anxiety | Risk of coughing during removal with an open dura |
| Blunting of high levels of noise from the power tools | Postoperative shivering on cessation of propofol while head fixed in pins |
| May reduce surgical procedure time | Risk of laryngospasm |

The anesthetist should try to minimize the oxygen flow in the nasal cannula (or face mask) and must remind the surgeon that they are working in an oxygen-enriched environment and should try to minimize the use of electrocautery and be prepared to extinguish a fire if one is to occur. Qualitative capnography can be captured continuously with a sidestream $CO_2$ monitoring device connected to the nasal oxygen delivery device. Placement of a temperature-sensing urinary catheter occurs when the patient is deeply sedated and provides continuous temperature monitoring.

As the patient may be lying in one position for a considerable amount of time it is a good idea to make the operating bed as comfortable as possible. Soft padding can be placed over the vulnerable joint areas such as the wrists, elbows, and heels; pillows may be placed between the knees if the patient is required to lie in a lateral position.

The head is supported with a three- or four-pin fixator frame in order to prevent head movement during surgery and maximize airway control during the sedation phase; this often requires compromise between a surgeon who desires a chin-to-chest position for exposure and the need to maintain an airway in an awake patient. (Note: our readers are encouraged to attempt to breathe while lying supine with their necks fully flexed in order to truly understand what the surgeons are requesting.)

Many sites advocate a scalp block for pain control while others consider the pain to be adequately controlled with skin wheels of local anesthetic. Adequate local anesthesia filtration of the fixator pin sites using 0.5% ropivacaine with epinephrine 1:200,000 (i.e., 5 mcg/mL) may be followed by a scalp block (suggested local anesthetic 0.5% ropivacaine with 2% lidocaine with 1:200,000 epinephrine). Consider dosing acetaminophen (IV) every 6 hours. It is also important to realize that even with a perfect scalp block and in the absence of somatic pain, many patients will still have a vague (or even severe) headache that will require opioid supplementation. Because the scalp block requires a large volume of local anesthetic (as much as 60 cc), it is important for the anesthesiologist to be vigilant in calculating dosages of local anesthetics, use agents with relatively less systemic toxicity (e.g., ropivacaine), and monitor for toxicity.

Regardless of whether an LMA is planned, final head position needs to be determined jointly between neurosurgery and anesthesiology so the airway is accessible thus allowing an LMA to be inserted emergently if needed. The use of some image guidance systems requires the patient's head be placed in an MRI-safe Leksell-type stereotactic frame and the patient transported to an appropriate MRI scanner in order to register the image guidance device as well as the underlying neurologic structures. If that frame includes a bar that crosses in front of the patient's mouth, a wrench capable of removing that bar must be present whenever the patient is wearing the frame.

IV ondansetron helps lower the incidence of nausea and vomiting while the patient's head remains fixed in the frame. Surgical drapes are then carefully positioned to allow continuous access by the anesthesiologist to the patient and the airway.

Despite having surgeons who would like the patient emerge from their general anesthetic (those with an LMA) or deep sedation quickly, there is an advantage to having the patient emerge gradually. At least one of us has greatly regretted using a quick wake-up technique early in their career; as the patient became startled and agitated and ripped themselves out of the head pins and removed important IV access. It is because of this possibility that a more gradual wake-up is desired and consideration given to having an extra IV placed (not connected to a bag and thus less likely to be removed by an agitated patient), which one can use to bolus an induction agent in the event of severe agitation.

**Table 223.5 ■ Intraoperative Complications During Awake Craniotomy With Management Strategies**

| Related Complications | Associated Problems | Management Strategies |
|---|---|---|
| Airway obstruction | Hypercarbia, increased brain swelling | Reduce sedation, nasal airway, LMA device |
| Seizures | Postictal state interferes with neurologic testing | Cold saline irrigation, propofol, levetiracetam, small dose of benzodiazepine |
| Poor pain control | Noncompliance | Local anesthesia, fentanyl |

Once the patient is allowed to waken prior to undergoing the speech and language and/or motor testing, reassurance, reorientation, and comfort measures such as oral mouth care are offered; if you have ever experienced cotton mouth, a swab goes a long way!

## Intraoperative Complications

The experienced anesthesiologist must be able to quickly recognize and treat complications related to this unique type of surgery. Table 223.5 depicts some of the relevant intraoperative complications with suggested perioperative management strategies. Although airway management is usually uneventful, sedation does carry the risk of airway obstruction and hypopnea. The possibility of clinical and subclinical seizures, (detected by continuous EEG monitoring), also exist, particularly during cortical stimulation. The surgeon will irrigate the field with cold saline to immediately terminate the seizure and may request a small bolus of propofol or midazolam. Difficulties may arise during the testing portion of the procedure if the patient remains postictal and drowsy, secondary to development of seizures during the surgery. The addition of a neurophysiologist talking to the patient during the operation may both distract and obstruct the anesthesiologist. Know your team and do not allow anyone to impede your care!

## Postoperative Care

Patients are usually fully alert and cooperative in the immediate postoperative period and can meet their family members before being transported to the neurologic postoperative care unit. Adequate analgesia can be provided to the patient once the scalp block begins to wear off.

In summary, awake craniotomies are becoming increasingly common procedures performed when neurosurgical resection may place eloquent areas of the brain at risk of injury. For an awake craniotomy procedure to be successful, the anesthesiologist must pay attention to many considerations including patient selection, airway management, pain control, and the onset of seizures. The OR team must work well and appear well-rehearsed—the patient is awake and anticipating the performance of their lifetime!

## TAKE HOME POINTS

- Maintain a calm environment.
- Good team working and communication is vital.
- Patient concordance is paramount!
- Sedation should be titrated to provide anxiolysis and analgesia.
- Avoid airway obstruction.
- Surgical drapes should be placed in a fashion that allows constant access to the patients' airway and eliminates claustrophobia.
- Blood pressure and CO must be controlled appropriately.
- Patient should be fully alert and cooperative during the examination.
- Seizures may occur with cortical stimulation and must be treated immediately.

## Suggested Readings


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# Anesthesia for the Pregnant Patient With Neurosurgical Disorder: These Cases Actually Do Happen in Real Life ….. and on the Oral Boards

Vincent Pagano, MD and Baskar Rajala, MBBS FRCA

A 25-year-old woman G1P0 at 11 weeks and 5 days gestational age with a history of migraine headaches is transferred to your hospital with a diagnosis of a new right frontal intracranial mass lesion. She was diagnosed after having progressively more severe migraines over the last 6 months. An MRI was performed (Fig. 224.1) which revealed a large right frontal lesion and she has been scheduled for resection of the intracranial mass. You are assigned to the case, how would you provide anesthesia and what are the anesthetic implications to the mother and the fetus?

## Introduction

Nonobstetric surgery during pregnancy is limited to urgent or emergent conditions but is relatively common. Fortunately, neurosurgical disorders are uncommon during pregnancy and surgical interventions are only performed when the pathology increases morbidity and mortality to both the mother and the growing fetus. The common neurosurgical indications include: traumatic brain injury (TBI), craniotomy for intracranial vascular lesions, resection of intracranial neoplasm, or surgery for spinal cord lesions or disc herniation.

The management of neurosurgical conditions requires a multidisciplinary approach with teamwork between the obstetrician, neonatologist, neurosurgeon, and anesthesiologist. The existing literature on the management of neurosurgical disorders during pregnancy is limited to case reports, case series, and small studies which lack significant evidence. Additionally, anesthetic management of these patients can be complicated by the physiologic changes that occur during pregnancy as well as by creating competing clinical scenarios where intervention on behalf of the mother may

lead to harm to the fetus and vice versa. Continuous communication between physicians and with the patient is pivotal to achieve higher medical care.

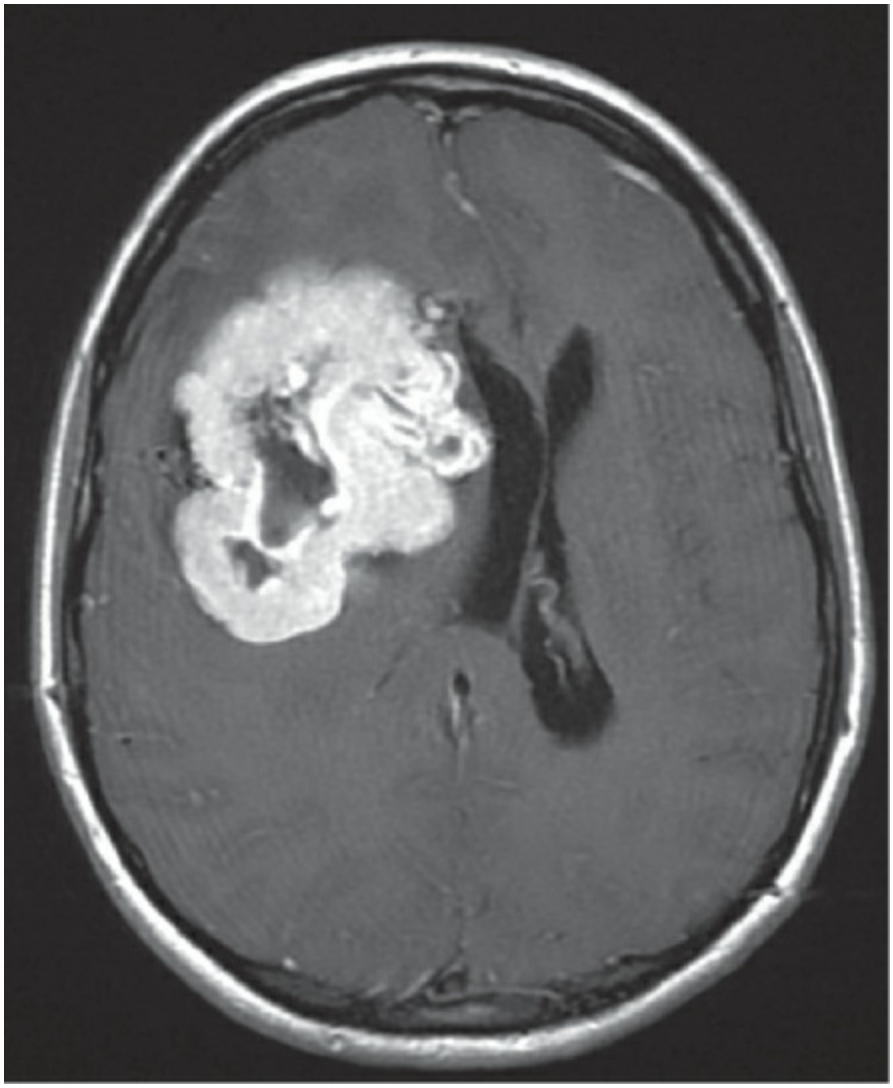

**Figure 224.1.** Irregular multilobulated, partially cystic, partially solid, partially enhancing 5 cm × 5.5 cm × 8 cm (cephalocaudad) mass centered in the right frontal lobe. The lesion is associated with local mass effect, vasogenic edema, and demonstrates midline shift.

## Physiologic Changes During Pregnancy

The pregnant woman undergoes various anatomical and physiologic changes to accommodate the growing fetus during pregnancy. These changes are discussed in the obstetrics section and only the changes related to CNS pathologies are discussed here.

## Timing and Method of Delivery

Timing and mode of delivery depend on the viability of the fetus (viable >24 weeks of gestation) and the nature of the neurosurgical condition. Urgent neurosurgical interventions should be performed at any time during pregnancy regardless of the

gestational age. For stable neurosurgical conditions, the timing and method of delivery varies depending on the clinical situation.

## Neurosurgical Conditions Requiring Neurosurgical Interventions During Pregnancy

### Traumatic Brain Injury (TBI)

Trauma during pregnancy complicates 5% to 20% of pregnancies and is associated with increased maternal mortality, and is the leading cause of maternal death and morbidity. Motor vehicle accidents, domestic violence, and falls are the most common causes of blunt injury during pregnancy. Although the initial assessment and management of resuscitation of a pregnant patient is similar to the nonpregnant patient, the physiologic and anatomical changes during pregnancy necessitate a modified approach. During resuscitation, it is important to prevent aortocaval compression during the second and third trimester of pregnancy. In the event of cardiac arrest, peripartum cesarean delivery performed within 5 minutes of cardiac arrest can improve the success of maternal resuscitation. The primary goal is maintenance or reestablishment of maternal neurologic and systemic homeostasis and early detection of neurologic deterioration. The secondary goal is to prevent the loss of the pregnancy.

### Intracranial Tumors

About 6 in 100,000 females will develop primary central nervous system tumors regardless of pregnancy. Although rare, the physiologic changes associated with pregnancy may exacerbate tumor growth and enhance patient symptoms. Intracranial tumors can present with a focal-neurologic deficit or seizure, and may be associated with signs and symptoms of increased intracranial pressure (ICP). Meningioma is the most common primary intracranial tumor and due to the presence of hormonal receptors, may progress rapidly during pregnancy. Similarly, during pregnancy, suprasellar and cerebellopontine angle tumors may be associated with rapid neurologic deterioration, and may require urgent neurosurgical decompression. Typical preoperative management of these patients includes steroid administration to reduce peritumor edema and, in turn, ICP. Steroids also have the added benefit of promoting fetal lung maturity by increasing surfactant production.

If a tumor is diagnosed during the first trimester of pregnancy and the patient is stable, pregnancy can be allowed to proceed to the early second trimester before surgery is performed. Surgery during the first trimester is associated with an increased rate of pregnancy termination regardless of the indication. Additionally radiotherapy, radiosurgery, and image-guided surgical interventions may be undertaken beyond the first trimester. If the patient is unstable, neurosurgery is indicated regardless of

gestational age. If a pregnant patient presents during the late second or third trimester and is clinically stable, gestational advancement may be allowed for possible vaginal delivery. In an unstable third trimester or term pregnant patient with impending herniation, delivery of the fetus by cesarean delivery under general anesthesia should be followed immediately by appropriate neurosurgical intervention.

## Intracranial Hemorrhage

Intracranial hemorrhage (ICH) is another important contributor to peripartum mortality. ICH accounts for 5% to 7% of all deaths during pregnancy, with pregnancy-induced hypertension playing an important role. ICH during pregnancy is most commonly due to subarachnoid hemorrhage (SAH) from rupture of an aneurysm or bleeding from an arteriovenous malformation (AVM), however intraparenchymal bleeds can and do occur. Spontaneous SAH occurs in 10 to 50 women per 100,000 pregnancies and it has a substantial maternal mortality rate of 40% to 80% as well as a 25% fetal mortality rate. Risk factors for SAH include advanced maternal age, pregnancy-induced hypertension, and parity. Risk of SAH is also increased at the time of delivery and is hypothesized to be due to increased plasma volume, cardiac output, and hormonal changes of the arterial wall.

Conservative management includes very close observation in an intensive care unit with continuous neurologic assessment and fetal monitoring by the obstetric team. Additionally, invasive monitoring, hemodynamic support with inotropes, and intubation for airway protection may be required. Triple-H therapy which includes hypertension, hypervolemia, and hemodilution may prevent vasospasm induced by SAH. Hemodynamic changes during pregnancy include a 40% to 50% increase in blood volume and cardiac output, and a 20% reduction in hematocrit due to hemodilution. Nimodipine can be used to prevent vasospasm but it should be titrated carefully to avoid maternal hypotension and subsequent fetal hypoxia.

For a ruptured aneurysm in early pregnancy, treatment should be administered first and the pregnancy may be allowed to continue to term. Surgical interventions include endovascular coiling and surgical clipping. Vaginal delivery can still be undertaken after these procedures. If rupture occurs beyond 34 weeks of gestation and during labor, delivery of the fetus by cesarean should be considered first, immediately followed by subsequent treatment of the aneurysm.

For an unruptured aneurysm, the management strategies depend on the size and location of the aneurysm. There is no consensus in the literature regarding the appropriate management of women with an unruptured aneurysm. A multidisciplinary team approach that includes discussion with the patient regarding treatment options and the risks of continuing the pregnancy is recommended.

## Back Surgery

Pregnant woman may require urgent spinal surgery to prevent permanent neurologic deficit. Cauda equina syndrome or progressive neurologic deficit can be due to a spinal cord tumor, infection or abscess, hematoma, or disc herniation. Prone positioning for spinal surgery can be challenging, but may be performed during the first and early second trimester. For the later stages of pregnancy, urgent cesarean delivery may be required prior to spinal surgery.

# Anesthetic Considerations of the Pregnant Patient During Neurosurgery

## Preoperative Anesthetic Considerations

A multidisciplinary approach involving the neurosurgeon, neuroradiologist, anesthesiologist, obstetrician, obstetric nurse, and neonatologist is recommended prior to any neurosurgical intervention.

Preoperative assessment should focus on the maternal physiologic changes during pregnancy such as airway examination, cardiorespiratory changes, gastric acid prophylaxis, and pregnancy-related conditions. Assessment should also focus on the underlying neurosurgical condition with respect to clinical presentation, current management strategies (steroids, diuretics, and anticonvulsants) and any underlying complications (raised ICP, seizures, and brain herniation).

Antiepileptic drugs (AEDs) have been associated with teratogenesis and anatomical anomalies such as neural tube defects on the developing fetus. During pregnancy seizure control should be managed jointly in consultation between obstetrician and neurologist. Maternal physiologic changes can modify pharmacokinetics of AEDs. Plasma concertation of AED should be monitored to guide dose adjustments and identify toxicity.

## Intraoperative Anesthetic Considerations

### Monitors and Access

Standard ASA monitors are required.

Intra-arterial catheters are preferred prior to induction of anesthesia to monitor and treat rapid hemodynamic changes. Central venous catheters may be required if vasoactive drugs are used during the procedure.

### Induction of Anesthesia

Rapid sequence induction with cricoid pressure is advised to prevent aspiration and hypoxia as early as the second trimester of pregnancy. Special attention must be given to

prevent aortocaval compression. Preoxygenate with 100% $O_2$; IV propofol (1 to 2 mg/kg) can be used for induction of anesthesia, and succinylcholine (1.5 mg/kg) for muscle relaxation. Smaller-size endotracheal tubes (6 to 6.5 mm) are recommended to prevent airway-related injury.

### Maintenance of Anesthesia

Neuromonitoring may be required for certain procedures. Maintenance of anesthesia may be achieved with TIVA, volatile anesthetics, or a balanced technique. The MAC of most of the volatile anesthetic agents are reduced by 25% during pregnancy. Moreover, volatile anesthetic agents reduce cerebral metabolic rate, **relaxes uterine muscle, and prevents preterm contractions.**

### Goals During Anesthesia

Prioritize maternal safety; avoid maternal hypoxia, hypocarbia, hypothermia, hypotension, and avoid preterm contractions.

- Maintain blood pressure within baseline limits. Hypotension will adversely affect fetal perfusion and outcome. Hypertension may worsen intracranial bleeding and raise ICP.
- Use antiemetic drugs and steroids as indicated.
- Mannitol up to 0.5 to 1 g/kg, furosemide can be safely given to reduce ICP.

### Emergence

An orogastric tube can be used to decompress the stomach prior to extubation. Avoid coughing on emergence. The patient should be extubated after neurologic assessment. If the patient is not following commands they may need urgent neuroradiologic imaging.

### Fetal Monitoring

The American College of Obstetricians and Gynecologists (ACOG) Committee on obstetric practice acknowledges the issue of nonobstetric surgery during pregnancy and the following are the recommendations:

- If the fetus is previable, ascertain fetal heart rate (FHR) by Doppler before and after the procedure.
- If the fetus is viable, at a minimum, continuous FHR and contractions monitoring should be performed before and after the procedure.
- Intraoperative electronic fetal monitoring may be appropriate when all of the following apply:
  - The fetus is viable.
  - Physically possible to perform continuous electronic FHR monitoring.
  - Obstetric surgical health care provider is available to intervene during surgery.
  - Woman has given informed consent for cesarean delivery for an emergency.

- The nature of the planned surgery will allow the safe interruption of the procedure to perform emergency delivery.

## Postoperative Anesthetic Care

Patient should be monitored closely in postanesthesia care unit (PACU) and followed by care in a neurointensive care unit.

- Continue routine postoperative care—maintain normal oxygen saturations, normothermia, baseline blood pressure, urine output, and DVT prophylaxis.
- Continuous neurologic assessment. Watch for raised ICP, vasospasm, and rebleed.
- Fetal monitoring and contractions monitoring as recommended by ACOG.

## TAKE HOME POINTS

- Neurosurgical disorders during pregnancy are uncommon but may cause increased morbidity and mortality to both the mother and the growing fetus.
- The management of neurosurgical conditions requires a multidisciplinary approach with teamwork between the obstetrician, neurosurgeon, and neuroanesthesiologist. Bring your best communication skills to cases like these!
- There are no evidence-based anesthesia guidelines for management of this patient population; management is primarily based on standard obstetric and neuroanesthetic principles.
- If a patient presents with an unstable neurosurgical condition, surgery is indicated regardless of gestational age.
- A sound understanding of the physiologic changes of pregnancy (increased airway edema, decreased FRC, increased blood volume and cardiac output, decreased hematocrit, and enlarged gravid uterus) will help to guide anesthetic management.
- These cases occur with some regularity on board exams, so be prepared for that. The most concise advice we can give to prepare for this type of question is to review the above and also remember that at a previable state, the priorities are maternal health, facilitating exposure/resection by the surgeons, and avoiding anesthetic agents and situations that are known to be teratogenic or damaging to the fetus.

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# Don’t Forget There’s No Such Thing as a Brain Transplant: Preventing Perioperative Stroke

Matthew C. Stansbury, MD and Laurel E. Moore, MD

Perioperative stroke is a devastating outcome following any surgery. In the general surgical population, perioperative stroke has an incidence of approximately 1:1,000, and for high-risk procedures, such as carotid endarterectomy (CEA), and coronary bypass procedures, this incidence approaches 3–6:1,000, which is roughly similar to the incidence of perioperative myocardial infarction (MI). **More recently, studies utilizing magnetic resonance imaging (MRI) are supporting the notion that up to 10% of general surgical procedures are associated with undetected or “silent” strokes, the long-term effects of which are unknown.** We feel that planning and delivering clinical care with the primary aim of avoiding perioperative stroke remain underappreciated and underpracticed. Large population-based studies are now providing information related to risk factors and perioperative associations, however, we have found there is a dearth of guidelines available to help anesthesiologists provide their patients with the best chance of making it through surgery without needing a brain transplant.

## Recognizing At-Risk Patients

Perioperative strokes are predominately of ischemic origin and, by definition, occur any time from the onset of surgery to up to 30 days after surgery. Discussion with patients and other perioperative and preoperative practitioners is important to help guide treatment and heighten awareness for patients who are at increased risk. Remember that the three most consistent major risk factors for perioperative stroke are:

- Previous history of stroke or transient ischemic attack (TIA)
- Age >65 years
- Renal disease

Other recognized risk factors include hypertension, a history of MI or congestive heart failure, and female gender. In the case of a patient with a recent history of stroke,

caution is critical to prevent further injury. The timing of elective surgery after stroke is a further topic of recent interest. Accepted practice has been to investigate the source of stroke (if possible) and delay elective surgery for 4 weeks, until the risk of further acute stroke is presumably returned to prestroke levels. **However, a recent large study has cast doubt on this practice and suggests that the poststroke elective surgery should be delayed for up to 9 months to minimize the risk of recurrent stroke and other major adverse cardiovascular events.** Serious discussion with the surgical team is important to optimize these high-risk patients and determine appropriate timing for elective surgery.

## Preoperative and Intraoperative Management

Many patients present for preoperative evaluation or to the preoperative area on numerous medications and often are unable to recall the specifics regarding dosing regimens. A few of these medications are of particular interest when considering perioperative stroke.

Anticoagulation/antiplatelet therapy: balancing the risk of hemorrhage with the risk of embolic events must be discussed with the surgical team! And though often thought of together, anticoagulation and antiplatelet therapies are individual therapies and hence must be discussed individually. Currently, consensus statements drawing evidence from observational studies recommend continuing anticoagulation therapy for procedures with low risk of bleeding. However, procedures that carry an increased risk of bleeding require patients to be removed from anticoagulation and bridged per protocol toward surgery. Postoperatively, guidelines suggest waiting 24 to 48 hours to restart therapy, depending on surgeon preference. Conversely, previous large observational studies initially suggested some protective benefit from continuing antiplatelet therapy. However, new important evidence indicates no clear benefit from continuing aspirin in the perioperative period. In fact, doing so virtually only increases the risk of major bleeding, which may mask any beneficial effect of ongoing platelet therapy. Also, based on these data, it is best to wait up to 8 days postoperatively before restarting antiplatelet therapy unless required for treatment of a thrombotic event. Future evidence will help to solidify this information, but for now it appears best to consider holding antiplatelet therapy.

Beta blockade and statin therapy: continuation of both beta blockade and statin therapy is recommended to protect against adverse perioperative cardiac events. However, when given in the perioperative period, noncardioselective beta blockers may be associated with an increased risk of perioperative stroke and death, possibly related to the potential for altered $beta_2$-mediated cerebral vasodilation. Use of intraoperative metoprolol has been linked to increased perioperative stroke and death.

At the present time, it is recommended that chronic beta blockers be continued in the perioperative period. For perioperative situations requiring acute beta-blocker management, shorter-acting cardioselective beta blockers such as esmolol should be selected. While statin therapy has been shown to decrease neurologic injury in CEA patients as well as poststroke patients, at present there is no evidence to support starting statin therapy in general surgery patients.

## General Anesthesia and Regional Techniques

Patients at risk for stroke undergo a variety of surgical procedures. Currently there is little support for regional anesthesia over general anesthesia with regard to perioperative stroke. There are some data to support the position that regional anesthesia may have a lower stroke incidence in joint replacement surgery only. When performing general anesthesia, concern has been expressed that nitrous oxide may induce increased homocysteine leading to increased clotting; however, no studies have supported that nitrous oxide increases the risk of perioperative stroke. In addition, hyperventilation is often used during neurosurgical procedures to decrease cerebral blood flow, raising concern with regard to decreased oxygen delivery. At this time, there is no clear evidence that induced hypocapnia increases the risk of stroke although hyperventilation should be used with caution in patients felt to be at risk for cerebral ischemia.

## Hemorrhage and Intraoperative Anemia

Both hemorrhage and anemia have been linked to increased risk of perioperative stroke. However, this relationship is difficult to analyze. Future research will need to be directed at discerning if the critical issue is the reduced hematocrit (and thus oxygen delivery), the hypotension associated with hemorrhage, or the fact that more complex surgeries tend to have greater blood loss that causes this association with stroke. There are data in the cardiac surgery population which support that both anemia per se as well as the number of units transfused are associated with perioperative stroke. Transfusion triggers should be discussed with the surgical team with regard to prevention of perioperative stroke. Patients on beta blockers may require a higher transfusion trigger because of restricted cerebrovascular responses to anemia.

## Hyperglycemia

While studies have shown increased neurologic injury in stroke patients with hyperglycemia, no definitive evidence has supported strict intraoperative glucose control. In fact, studies have shown that intensive glucose control increased the risk of

stroke despite no increase in hypoglycemic episodes. Currently the recommendation is to maintain blood glucose between 60 and 180 mg/dL.

## Intraoperative Hypotension

Widely accused of being a cause of perioperative stroke, the limited number of watershed infarcts as well as the low incidence of strokes evident at emergence from anesthesia argue against intraoperative hypotension as a primary cause of perioperative stroke. Recent studies looking at blood pressure control have pointed to decreases in mean arterial pressure (30% or more below baseline) as increasing the risk of stroke, but only minimally. While it is prudent to maintain blood pressure intraoperatively within 20% of the patient's "baseline" pressure, intraoperative hypotension is clearly not the sole determinant of perioperative stroke but may serve as a marker for those patients who are at risk for further hypotension postoperatively when not in the closely monitored OR or postanesthesia recovery unit. That said, there is an important point to be made regarding intraoperative hypotension and the clear association between the "beach chair position" and cerebral ischemia. In seated patients, there is a clear gradient between perfusion pressures measured at the brachial artery (or even worse, the lower extremity!) and the brain stem. Induced hypotension for shoulder procedures in the beach chair position should **never** be considered acceptable and the gradient between the arm and head should be kept in mind when determining an acceptable blood pressure for the procedure.

## Postoperative Assessment and Treatment of Stroke

The anesthesiologist must be able to rapidly and accurately assess for stroke. Many quick and simple neurologic examinations have been developed with the National Institutes of Health Stroke Scale/Score (NIHSS) being the most definitive, see http://www.ninds.nih.gov/doctors/NIH_Stroke_Scale.pdf. It is incumbent upon the anesthesiologist to be familiar with the patient's prior-known neurologic deficits (weakness, visual loss, etc.) in order to adequately perform these assessments. In addition, institutions are encouraged to maintain a stroke team for rapid response. Knowledge of how to activate and engage your institution's stroke team when concerned about perioperative stroke is essential. As the old adage says "time is brain," and remember there's no such thing as a brain transplant.

### TAKE HOME POINTS

- Perioperative stroke is a devastating complication of surgery and anesthesia that is probably more common than we recognize.

- There are clear patient risk factors for perioperative stroke—previous history of stroke or TIA, age >65, renal disease, hypertension, history of MI or congestive heart failure, female gender.
- The anesthesiologist must accept that tension exists between minimizing hemorrhagic and minimizing embolic events. These tensions should be recognized, discussed, and resolved with other perioperative providers, including the surgeons. Remember that anticoagulation therapy and antiplatelet therapy are individual therapies and so must be considered individually. Recent data support holding antiplatelet aspirin therapy during the perioperative period until 8 days postoperatively.
- The association of perioperative stroke and any other given perioperative event or risk factor is less clear and in cases where a risk association has been suggested, the detailed risk ratios are difficult to analyze. This lack-of-certainty includes choice of anesthetic technique, intraoperative anemia, hyperglycemia, and intraoperative hypotension.
- There is however, a clear association between the beach chair position and cerebral ischemia and induced hypotension in the beach chair position should never be considered.
- Knowledge of the patient's preoperative neurologic status and deficits is imperative, as is the knowledge of how to assess for stroke using a standard assessment score or scale. A detailed description of the NIHSS can be found at http://www.ninds.nih.gov/doctors/NIH_Stroke_Scale.pdf. If you are just starting to learn about the stroke assessment scales, brief descriptions and overviews of the NIHSS are readily viewable online (but keep in mind that this may be Wikipedia, so review the more rigorous presentations as well).

## Suggested Readings


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# Anesthesia for Emergent Neurointerventional Procedures: "Neurology Just Called, They Have a Stroke Patient for Thrombectomy Down in Neuroradiology, Start Time is 2 AM"

Laurel E. Moore, MD

A 71-year-old man with a history of diabetes and hypertension is being transferred from an outside hospital for thrombectomy. He presented to an OSH with aphasia—a CT scan of his head was negative for a bleed but showed a hyperdense left MCA. He was last known well at 11 am, received tPA at the OSH at 12:17 pm. He is alert but oriented only to self.

## Introduction

Interventional neuroradiology is one of the most exciting (really!) and rapidly advancing areas of medicine at present. It is a clinical practice area that is of interest to the anesthesiologist because the majority of these complex procedures require anesthetic care for patient comfort and immobility as well as hemodynamic and pharmacologic management. A huge topic, I will try to condense a large quantity of information into a "what do you have to know" document for when you get that emergent acute ischemic stroke (AIS) in the middle of the night.

## General

The neurointerventional suite is inherently in a remote location. Thus preparations must be made and a system for rapid communication and immediate assistance must be in place. Because some of these procedures are truly emergent (AIS intervention and cerebral vasospasm), it is recommended that at least one interventional suite be outfitted with a checked anesthesia machine, 3–4 channel monitors, and anesthesia cart at all times.

## General Considerations for All Neurointerventional Procedures

1) Pharmaceuticals available should include:
   a. Anticoagulant and antiplatelet therapies including heparin, protamine, glycoprotein IIb/IIIa inhibitors such as abciximab (ReoPro®) and oral antiplatelet agents ASA and clopidogrel (which is loaded with a 300-mg dose that is available as a rectal suppository).
   b. Total intravenous anesthesia (TIVA) is commonly used to permit neurophysiologic monitoring and rapid emergence from anesthesia, so infusion pumps and agents appropriate for TIVA should be immediately at hand.
   c. Pressors including phenylephrine, ephedrine, and possibly vasopressin and norepinephrine.
   d. Antihypertensive use is generally limited to subarachnoid hemorrhage (SAH) but rapidly titratable agents such as nicardipine should be immediately available.
2) Equipment needed for arterial and intracranial pressure monitoring.
3) ACT machine and a system for glucose monitoring. Realize that protamine should be available for heparin reversal, but that reversal is usually not as aggressive as in a cardiac case.
4) A plan for postprocedure disposition (PACU or ICU?).
5) **Hemodynamic goals, particularly goal mean arterial pressure (MAP), should always be discussed with the neurointerventionalist preprocedure and adjusted during and after the procedure**.
6) If patients are on antiplatelet therapy preprocedure the availability of platelets should be confirmed in case of a catastrophic hemorrhage. Blood products should be available for any patient with SAH as they may require open craniotomy for clipping. While a vascular injury related to access could lead to blood loss, intracranial bleeding rarely leads to transfusion.
7) Comfortable personal lead and a lead shield should always be present for the anesthesiology team due to the long duration and heavy radiation associated with these procedures. Leaded glasses should be considered for those regularly caring for patients in IR. Remember that an increased distance from the radiation source provides additional protection.

## Emergent Neurointerventional Procedures

Common emergent procedures performed in the neurointerventional suite include thrombectomy for AIS, coiling for a ruptured aneurysm, and management of cerebral vasospasm following SAH.

## Acute Ischemic Stroke

Systemic thrombolysis administered within 4.5 hours of stroke onset in patients who otherwise meet criteria clearly improves neurologic outcome. In 2013, several major studies were published all questioning the effectiveness of endovascular management of AIS beyond systemic thrombolysis (tPA). While a discussion of the pros and cons of endovascular management of AIS is beyond the scope of this chapter, there are several indications which may support acute intervention: (1) Large vessel occlusion—for example, proximal middle cerebral artery occlusion may be poorly responsive to systemic thrombolytics because of the size of the clot; (2) Patients ineligible for systemic thrombolytic therapy (e.g., postsurgical patients); and (3) Patients beyond the 4.5-hour window for systemic tPA with devastating strokes. Endovascular management includes both intra-arterial thrombolysis and mechanical thrombolysis. An excellent consensus statement by the Society of Neuroscience in Anesthesiology and Critical Care was published in 2014 (see below) and should be referred to for more detail. A few important points:

) These are true emergencies—patients lose almost 2,000,000 neurons/min; so literally, "Time is Brain!" Other than induction of general anesthesia, nothing including a lack of medical information or arterial line insertion should delay femoral artery cannulation by the interventionalist. Additional lines (including a radial arterial line) can be placed while the interventionalist cannulates the groin but don't be afraid to ask to monitor off of their sheath; the presence of tPA should influence line location and the need to assess for local bleeding.

) Although the data are clearly skewed by selection bias, patients undergoing conscious sedation (vs. general anesthesia) do better neurologically. If the patient is adequately cooperative to tolerate sedation by all means proceed in this manner. The procedure starts sooner and brain perfusion is better maintained in an awake patient.

) Patients with posterior circulation ischemia unable to protect their airways and aphasic patients unable to understand directions are two subsets of patients who may require general anesthesia and endotracheal intubation.

) Clearly these are high-risk patients with multiple comorbidities. Ask the stroke neurologist in attendance to try to access additional medical information while you provide anesthetic care.

) Hypotension is the enemy! Given their dependence on (probably limited) cerebral collateral flow, patients with AIS do not tolerate hypotension. Although the data are weak, a systolic pressure maintained between 140 and 180 mm Hg is a reasonable goal but these patients are often "uncapped," that is, without an upper blood pressure limit in the acute period.

) Normocapnia and normoglycemia should be maintained.

## Cerebral Aneurysm Coiling Following Subarachnoid Hemorrhage

Due to the ubiquity of cranial CAT scans, the majority of cerebral coilings are now performed electively for unruptured aneurysms found coincidentally on surveillance CT. For patients who have suffered an SAH, however, open neurosurgical clipping or endovascular coiling of the ruptured aneurysm remains urgent due to the risk of rerupture. Furthermore, until the aneurysm is secured, subsequent management of cerebral vasospasm is limited. A few differences from elective cerebral aneurysm coiling include:

) Patients by definition are sicker and frequently impaired neurologically. Survival from SAH is closely related to the neurologic condition (Hunt–Hess score) of the patient on admission.

) Patients are not pretreated with antiplatelet agents prior to undergoing coiling due to the obvious hemorrhagic risks. As a result there may be a high risk of thromboembolic complications post intervention.

) Risk of recurrent SAH is probably greatest with deployment of the initial 1 to 2 "framing" coils.

) These are always done with general anesthesia. Hypertension must be avoided during induction and intubation given the risk of aneurysmal rupture. TIVA is commonly administered to accommodate neurophysiologic monitoring.

) Although the risk of major hemorrhage is small compared to open clipping (you can only bleed so much into your head), it is still a catastrophic event with significant implications for intracranial pressure and dysrhythmia. Two good IVs are essential for anesthetic administration and resuscitation if needed.

) Arterial access is routine, but if it is difficult you might monitor off of the femoral sheath.

) Although data are limited, a systolic pressure of 140 mm Hg is generally considered the acceptable "upper limit" in the unsecured aneurysm. It is important to also remember that patients suffering severe SAH probably don't autoregulate normally so hypotension is equally bad in this population of patients. It is reasonable to review preprocedural blood pressures and try to keep within this range; if the patient has consistently been running systolics of 150 mm Hg this might be an appropriate goal. Again, data are limited to guide our practice here.

) Patients frequently have external ventricular drains (EVDs), so management of these catheters including how to monitor intracranial pressure should be familiar or you should ask for help. EVDs should NEVER be opened to air in an attempt to "zero" your transducer. Again, ask for help if you are unfamiliar with these devices. Keep in mind that abruptly lowering an EVD system that is open to drain will increase the transmural pressure gradient and lead to rerupture, which can be catastrophic.

9) Once the aneurysm is coiled it is considered "secure." While smooth emergence remains the goal, the patient should be protected against rerupture of their aneurysm.
10) Rapid neurologic evaluation post emergence should be part of the anesthetic design.
11) The large catheters introduced into the cerebral circulation often cause microembolic strokes.

## Endovascular Management of Cerebral Vasospasm

Like AIS, management of cerebral vasospasm is truly emergent as these patients are clearly suffering strokes. Clinical vasospasm, which is associated with changes in arterial wall structure, can occur starting 4 to 5 days post SAH and can continue for as long as 2 to 3 weeks post hemorrhage. The severity of cerebral vasospasm is related to the amount of clot in the subarachnoid space (search Fisher Scale for details), so to some extent the complication is predictable but there appears to be a subset of patients who suffer particularly malignant vasospasm with significant implications for neurologic outcome. When patients present for endovascular management of vasospasm (either angioplasty or intra-arterial vasodilator administration or both to affected arterial segments), they have generally failed standard management of vasospasm which includes calcium channel blockers and "triple H" therapy (hypertension, hemodilution, and hypervolemia). They are generally neurologically impaired and suffering the cardiovascular and pulmonary effects of "triple H" therapy. In a word, they are REALLY SICK. A few specific considerations:

) As patients are generally on pressors to maintain a high MAP, patients should arrive to you with an arterial line in place. Arterial pressure monitoring is essential.
) Equally essential is central access. While patients may meet "goal MAPs" in the ICU on a phenylephrine infusion administered peripherally, once they are under general anesthesia and vasodilators are being administered, patients rapidly escalate to requiring vasopressin and/or norepinephrine infusions. If patient arrives without central access, rather than delay the procedure, ask the neurointerventionalist to place a femoral venous line at the same time she/he accesses the femoral artery.
) These procedures are generally done with patients intubated for hemodynamic stability and akinesis—if the patient moves during coil deployment into the aneurysm, it may likely rupture and the patient will not do well.
) As for all neurointerventional procedures, discuss goal MAP in advance with the neurointerventionalist. In this setting, goals are frequently as high as 120 to 130 mm Hg.
) Vasodilators administered intra-arterially frequently cause systemic drops in blood pressure which must be treated with escalating doses of pressors. This is especially true of verapamil, a negative inotrope. It is possible to reach a point that you feel the patient has "maxed out" on pressors and you should discuss with the

neurointerventionalist either that they should accept a lower level of MAP or consider ceasing vasodilator administration. The goal of this therapy is to maximize oxygen delivery to an ischemic region of the brain and if you feel you have reached the point when you are actually harming the patient with your therapy it is important to discuss this with the other caretakers including interventionalist and neurocritical care attending.

) Hypervolemia is associated with pulmonary edema and has been abandoned in favor of euvolemia in an effort to optimize cardiac output and oxygen delivery.

## Conclusion

The neurointerventional suite is an exciting clinical assignment with unsurpassed clinical exposure to neuroanatomy and neurophysiology. It is, however, unfamiliar territory to many of us. By having a suite prepared in advance for the care of critically ill neurosurgical patients as well as a neurointerventional team that works well together it is possible to provide excellent clinical care even in the most trying circumstances. One final point: In the technically advanced neurointerventional suite it is particularly important to maintain communication with the patient's family throughout the procedure.

### TAKE HOME POINTS

- Time is brain—2,000,000 neurons per minute!
- The circle of Willis is functionally intact in only ~40% of patients. Do not rely upon it to drive perfusion.
- "Patients with aneurysms have aneurysms," that means more than one! Even if the one that ruptured is secured, there may be another aneurysm just waiting to rupture.
- Any of these etiologies may trigger neurocardiogenic depression necessitating inotropes to drive cardiac output.
- You may review Fisher Scale to evaluate CT scans for the risk of vasospasm and Hunt–Hess Scale for patient mortality.
- Realize that you aren't the only one who is dosing heparin, as the flush used to stop the femoral sheath from clotting is also heparinized.

## Suggested Readings

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# Encephalopathy and Intracranial Hypertension in the Acute Liver Failure Patient Are Not the Same Thing!

Pavan K. Battu, MBBS DA FRCA and Laurel E. Moore, MD

Acute liver failure (ALF) is defined as a sudden and severe liver cell dysfunction leading to coagulopathy and encephalopathy within 26 weeks of jaundice in a patient without pre-existing liver disease. Hepatic encephalopathy is characterized by deterioration in the level of consciousness. The encephalopathy caused by ALF is secondary to metabolic changes that are almost always reversed with transplantation or spontaneous recovery. However, in some patients, encephalopathy is also associated with a complex pathology that involves rise in intracranial pressure, reduced cerebral perfusion, and physical brain injury with irreversible brain damage. Intracranial hypertension in patients with ALF is one of the primary causes of morbidity and mortality along with multiorgan failure and infection. Remember that encephalopathy and intracranial hypertension are associated, but not the same thing.

## West Haven Criteria for Encephalopathy

| | |
|---|---|
| Grade 0 | No abnormality detected |
| Grade 1 | Trivial lack of awareness, euphoria or anxiety, shortened attention span, impairment of addition or subtraction |
| Grade 2 | Lethargy or apathy, disorientation to time, obvious personality change, inappropriate behavior |
| Grade 3 | Somnolence to semi stupor, confusion, gross disorientation, bizarre behavior |
| Grade 4 | Coma |

The risk factors for intracranial hypertension are thought to be younger age and more severe encephalopathy. It is also more commonly seen in patients with rapidly

progressive encephalopathy and seems to vary with etiology of liver failure. For example, it appears that intracranial hypertension and cerebral edema are associated with acetaminophen-induced liver failure and certain viral etiologies of liver failure.

## Pathophysiology of Raised ICP in ALF

The exact pathogenesis of intracranial hypertension in ALF remains unclear but it is likely that a number of interrelated mechanisms contribute. These possibilities include:

) Ammonia, synthesized by gut microorganisms, is detoxified by cerebral astrocytes to osmotically active glutamine causing osmotic cerebral edema.
) Cerebrovascular autoregulation is lost in patients with ALF resulting in hyperemia.
) Systemic inflammatory responses may contribute to altered cerebral blood flow and intracranial hemorrhage. The rise in ICP may also contribute to classic brain herniation as well.

## Intracranial Pressure Monitoring

Indications for placement of an intracranial pressure (ICP) monitor remain one of the most contentious issues in managing the patients with ALF. Risk of bleeding from ICP monitor is reported as high as 4% to 20% depending on the depth of insertion and has resulted in death in 5% of cases. Because of the inherent risk of bleeding, ICP monitoring should be performed when estimates of pressure are likely to be of value in management. ICP monitor placement should be undertaken by centers with appropriate experience and support including the ability to manage severe coagulopathy. The US Acute Liver Failure Study Group recommends the placement of an ICP monitor in patients listed for transplantation with grade III to IV hepatic encephalopathy. Some centers use ICP for prognostication of nontransplant patients in whom intense medical therapy offers a reasonable likelihood of survival.

To minimize the risk of developing cerebral edema in patients with ALF, the following measures should be undertaken:

## General Measures

) Head position: Elevate head of bed 30 degrees and maintain head in neutral position.
) Avoid excessive stimulation: Patients should be nursed in calm environment and sedation should be instituted early to prevent surges in ICP and propofol is the preferred agent.
) Metabolic derangements such as hypoxia, hypercapnia, hyperglycemia, and hyperthermia increase ICP and hence should be avoided.
) Infection: Periodic surveillance cultures are recommended to detect bacterial and

fungal pathogens as early as possible.

## Specific Measures

1) Treatment of circulatory dysfunction: The initial treatment of hypotension should be with intravenous fluid boluses of normal saline to attain euvolemia. Blood pressure should be maintained within a narrow range to achieve a CPP of 60 to 80 mm Hg to prevent hypoperfusion on one hand and further hyperemia on the other. Volume-resistant hypotension should be treated with vasopressors. Norepinephrine is the preferred vasopressor since it produces consistent and predictable increase in cerebral perfusion. Vasopressin and its analogs should be used cautiously in encephalopathic patients with intracranial hypertension.
2) Renal failure: Ensure adequate steps protect renal function by maintaining adequate hemodynamics, avoiding nephrotoxic agents such as aminoglycosides and nonsteroidal anti-inflammatory drugs, and by the prompt identification and treatment of infection. When dialysis is needed continuously, modes of renal replacement therapy should be used.
3) Management of intracranial hypertension:

A. Mannitol: Mannitol (0.5 to 1 mg/kg) boluses should be considered when the ICP is 25 mm Hg in patients with preserved renal function. Serum osmolality should be checked every 6 hours and boluses may be repeated if ICP is >25 mm Hg and serum osmolality is less than 310 mOsm/L.

B. Hypertonic saline: Hypertonic saline in various preparations and dosing strategies has been employed to treat ICH. Induction and maintenance of hypernatremia using hypertonic solution to maintain serum sodium levels of 145 to 155 mmol has been shown to reduce the incidence and severity of ICH in patients presenting with ALF.

C. Hypothermia: Limited experience in humans with ALF supports the use of hypothermia (cooling to core temperature of 33° **to** 34°C) as a bridge to liver transplantation or to control ICP during transplant surgery. Potential deleterious effects of hypothermia include increased risk of infection, coagulation disturbances, and cardiac arrhythmias.

### TAKE HOME POINTS

- Intracranial hypertension is a significant cause of morbidity and mortality in patients with ALF. The exact pathogenesis is unknown.

- The use of intracranial pressure monitoring is controversial.
- These patients require sedation and propofol is the agent of choice.
- Expect circulatory dysfunction!
- Specific treatment involves mannitol, hypertonic saline, and hypothermia.

## Suggested Readings


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## SECTION XI

# CARDIAC ANESTHESIA

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# Introduction

Edwin G. Avery IV, MD

If I were to summarize what it is like to work as a cardiac anesthesiologist, I would say the following: Being a good cardiac anesthesiologist is like being a farmer, there is always work to do. Like many anesthesiologists, our days start early and frequently end late. Our patients are never healthy and our surgical colleagues are a (unique?) breed of physician who (sometimes?) take some getting used to in terms of working comfortably with them. With that said, I would like to share some of my ideas and opinions about how one gets through the working day of a cardiac anesthesiologist.

To begin, it makes sense to know what one is going to be up against before entering the operating room. I find out what case I am scheduled for the following day and I like to know who I am working with on both sides of the ether screen; if there are special considerations, I will communicate with both my anesthesia physician extender and cardiac surgical colleague to discuss these with them (better to discuss it beforehand rather than lock horns with our surgical colleagues in the heat of battle). Another preparatory item is that, if I am on call the following day and know I will be on my feet all day and into the wee hours, I will wear compression socks that day because we stand up so much and I really think it helps with leg fatigue (I also keep a clean pair in my locker for surprise long shifts).

In my practice, the operating room is set up the day prior by the anesthesia physician extender—I take advantage of this and let them know what I want, hanging for induction drugs. For example, for aortic stenosis and coronary cases, I always want phenylephrine in line running at a low dose to keep afterload up, or for severe regurgitant valvular lesion cases I like dopamine running at 3 to 5 μg/kg/min to prevent bradycardia and to counterpunch the sympathectomy that accompanies induction.

My day-of-surgery routine includes meeting with the patient and family to get all the needed information and to convey an honest set of expectations to them about what their recovery will be like. I cannot seem to avoid the phrase “when you first wake you are going to wonder why I ever signed up for this surgery as I feel worse now than I did before the surgery” and “because of all the antibiotics we give you any food you eat is going to taste like hospital food so you may as well eat hospital food.” I hand them one

of my business cards in the event they have questions after the surgery. I always check the operating room setup before we take the patient back and this is a great way to avoid running back and forth to the anesthesia work room or needlessly bothering the busy anesthesia technicians.

Once the patient gets in the operating room, I have a few other suggestions that are helpful. Put Mastisol® on the skin for your cerebral oximetry sensor pads and place two pieces of tape along their edges to keep them from coming off during rewarming as many patients will sweat a lot during this time. Use an 18-gauge angiocatheter "through and through" technique with ultrasound guidance for the central vein cannulation when working with trainees (I think it is safer to poke two holes in the vessel than to have them swinging the thin wall needle around in there slicing up the vein). Floating a pulmonary artery catheter is done most effectively with the catheter's natural curve facing the left shoulder and using a flow-directed technique (i.e., quicker, consistent, rapid pushes of the catheter until it enters the pulmonary artery as opposed to a slow, dragging pace). Transesophageal echocardiography (TEE) probe insertion should be slow and deliberate. I hang the probe around my neck and use my left hand to perform a gentle jaw lift and use fingertip pressure of the slightly anteflexed probe to advance it through the upper esophageal sphincter.

Complete TEE exams are a must both before and after bypass no matter what the procedure. If you neglect to "run the aorta" after bypass and miss an aortic dissection, the patient can die in the intensive care unit from something that could have been readily dealt with in the operating room. For challenging inductions like cardiac tamponade and pulmonary embolectomy cases, I induce with etomidate and run a dopamine drip at 5 to 10 μg/kg/min to counterpunch the sympathectomy; it is also important to have the surgeon and perfusionist in the room ready to go prior to inducing. Learn the surgical procedure and perfusion technology with as much detail as you can gather; this helps you be better at your job and assist others with theirs when the time comes and things are not going well.

Know your surgeon's capabilities and suggest getting help if they are in over their head—in my experience they are much more likely to agree to accept help than they are to ask for it. **Always stay vigilant in the cardiac operating room and never forget that a good cardiac surgeon deserves a good cardiac anesthesiologist while a mediocre cardiac surgeon needs a good cardiac anesthesiologist!** When things are not going well in the operating room and it seems as if you are only chasing one esoteric action with another, stop and take a step back to look at everything that is going on and you will likely find something you missed. Remember that there are no mysteries in cardiac surgery … only mysterious cardiac surgeons.

Lastly, it is becoming more and more apparent that one of the most helpful things we

can do for our cardiac surgical patients is to avoid exposing them to allogeneic blood components. I think of red blood cell transfusions like an organ transplant without giving all the steroids that solid organ transplant patients get. If you are having a love affair with the 30/10 (hematocrit/hemoglobin) numbers, it is time to end it before anyone else gets hurt!

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# Cardiac Surgical Coagulopathy—You'll Need the Blood Bank and a Genie in a Bottle

Edwin G. Avery IV, MD and James R. Rowbottom, MD

A 75-year-old female with multivessel coronary disease and severe tricuspid regurgitation, is undergoing coronary bypass grafting (×6) and a tricuspid valve repair on cardiopulmonary bypass (CPB). The patient's preoperative international normalized ratio (INR) was found to be slightly elevated with a value of 1.3. Aminocaproic acid was given pre-CPB in anticipation of a long pump run, which was 187 minutes. Following heparinase thromboelastography (TEG®)-confirmed heparin neutralization, the floodgates appear to burst open and profuse bleeding from the surgical field is apparent along with a significant volume requirement. The surgeon notes that there is no "surgical bleeding," only diffuse hemorrhage from all tissues and suture lines. The activated clotting time (ACT) is significantly elevated from baseline and the Hb = 10.8 mg/dL. The surgeon requests immediate administration of fresh frozen plasma (FFP), cryoprecipitate (Cryo), platelets, red blood cells (RBCs) and "rescue activated recombinant factor VII (rFVIIa)" at a dose of 90 μg/kg. Post-CPB coagulation studies are pending while the TEG continues to process (see Chapter 54). Allogeneic blood components and various factor concentrates are immediately available. What is the best course of treatment?

**Answer:** This patient presented with severe tricuspid regurgitation that can cause hepatic congestion and hepatocellular dysfunction; the preoperative INR of 1.3 suggests that up to 65% of the soluble coagulation proteins are deficient as the INR will not rise until approximately 40% to 65% of the soluble coagulation factors in the extrinsic/common pathway are deficient. This low level of coagulation proteins is likely insufficient to control hemorrhage in this setting, so you should administer 2 to 4 units of FFP pronto and this will help correct the coagulopathy and maintain intravascular volume. Remember that RBCs are generally not indicated when the Hb >7.0 mg/dL.

Point-of-care testing (POCT) TEG will confirm this coagulation defect and set a goal of

keeping the functional platelet count >100th/mm$^3$. Even if the preoperative platelet count was normal the long CPB run and diffuse bleeding suggest that platelets should be administered. Administer 1 to 2 pheresis platelet units through a nonwarmed, filtered line and **do not** inject concentrated calcium or epinephrine in the same intravenous line as the platelets, as it may activate them in the tubing!

**With all due respect to our surgical colleagues, "rescue rFVIIa" is not indicated until hemorrhaging patients have received at least two rounds of allogeneic hemostatic products without evidence of improvement in the bleeding.** Further, rFVIIa may be effective at much lower doses (e.g., 35 μg/kg) than the package insert recommendation of 90 μg/kg which is the dose for bleeding hemophiliacs. If cross-matched hemostatic products are not immediately available consider activating your institutional massive transfusion protocol (MTP) and administer RBCs, FFP, and platelets in a 1:1:1 ratio; however, algorithmic POCT-guided therapy, for example, TEG or rotational thromboelastometry (ROTEM®) is currently preferred over MTP use as the issued components may not be type specific and will not be cross matched thus increasing the risk of allergic reaction. TEG/ROTEM can be useful as it will help diagnose the specific nature of many coagulopathies within about 15 to 20 minutes.

Cardiac surgical patients are among those most likely to experience perioperative coagulopathy. These patients have temporally variable CPB exposure and regardless of the CPB circuit employed their coagulopathy has been shown to correlate with the length of time spent on CPB (i.e., there is an increasing incidence of coagulopathy as CPB time increases). **CPB times exceeding 3 hours should alert clinicians to the potential for development of a significant coagulopathy.** Blood to CPB element interfaces within circuitry initiate activation of systemic inflammatory pathways that are tied to the coagulation system and can provoke imbalance toward hypocoagulability. CPB-associated mechanical trauma to the blood elements causes anemia, thrombocytopenia, and a functional platelet defect (i.e., shear stress injury activates platelets). Dysfunctional platelets are quantified with a complete blood count (CBC) but do not actively contribute to hemostasis. **The platelet count will frequently underestimate the need for a platelet transfusion because CPB creates a dysfunction-based thrombocytopenia.** Additionally, cardiac surgery reproducibly creates a fibrinolytic state that may only be partially overcome through the pre-CPB initiation of antifibrinolytic agents. Further, since many cardiac surgery patients have undergone previous percutaneous coronary interventions or present with a low cardiac output syndrome, they are routinely treated with antiplatelet and/or antithrombotic agents.

Antecedent antithrombotic/antiplatelet therapies are associated with increased postoperative hemorrhage and the increased need for transfusion of allogeneic blood

products. Several antithrombotic agents (e.g., low–molecular-weight heparin) and antiplatelet agents (e.g., ADP antagonists) cannot be effectively neutralized pharmacologically and will require the administration of allogeneic blood components to overcome their effects. Other antithrombotic agents such as oral factor X inhibitors may be neutralized by administration of a balanced prothrombin complex concentrate (i.e., contains balanced amounts of factors II, VII, IX, X, proteins C and S, and antithrombin III). Like rFVIIa, prothrombin complex concentrate is another "genie in a bottle." Use of a balanced prothrombin complex concentrate to reverse a factor X inhibitor or to treat cardiac surgery–associated coagulopathy is an off-label use of the product and has been associated with thromboembolic complications, so be careful! As with rFVIIa, much lower doses of the balanced prothrombin complex concentrate (KCentra®) are used to treat cardiac surgical coagulopathy (i.e., 20 to 25 IU/kg of factor IX activity) than are recommended in the package insert for its labeled indication (i.e., Coumadin reversal). **Off-label use of factor concentrates (prothrombin complex concentrates or rFVIIa) to treat cardiac surgical coagulopathy should not be pursued until at least two rounds of banked hemostatic allogeneic blood products have been administered without improvement.**

The potentially costly and morbid consequences of mistreating the coagulopathy observed in the clinical situation described above calls for the use of POCT as well as standard central laboratory hematology/coagulation tests, such as Hb, platelets, INR, and activated partial thromboplastin time (aPTT). Please remember that the isolated use of the INR is not a strong predictor of postoperative hemorrhage in this setting. The aPTT may be a better test to assess coagulopathy severity but does not distinguish between residual heparin effects. The ACT is the POCT that is used in cardiac surgery to monitor the effect of blood heparin levels and may correlate with the severity of coagulopathy. It does not correlate well with plasma heparin levels in hypothermic, hemodiluted patients on CPB. It is also a poor test of trace amounts of heparin and thus is not a good test to distinguish coagulopathy from residual heparin effects. It may be prolonged in patients with marked thrombocytopenia. **Given its multiple shortcomings, the ACT is not a good test to diagnose the specific etiology of cardiac surgical coagulopathy.**

TEG/ROTEM are among the more useful POCTs to rapidly evaluate the integrity of the coagulation cascade. Both assays allow semispecific evaluation of the functional level of soluble coagulation proteins, functional fibrinogen levels, functional platelet levels, the presence of fibrinolysis and through the use of specialized assays the degree of platelet inhibition related to arachidonic acid inhibitors and ADP antagonists. Several cardiac surgical trials have confirmed that use of TEG with a transfusion algorithm is a more effective means to reduce the amount of transfused blood

components compared to physician discretion.

Cardiac surgery–associated hypofibrinogenemia can be a major contributor to hemorrhage as it functions to form the proteinaceous scaffolding of a blood clot. Each unit of FFP contains the equivalent amount of fibrinogen found in one unit of Cryo. If TEG/ROTEM or laboratory testing reveals dys- or hypofibrinogenemia, then a target fibrinogen level of >200 mg/dL in a bleeding cardiac surgical patient is the goal and Cryo administration is indicated. In the absence of readily available Cryo the use of fibrinogen concentrate (RiaSTAP®) should be considered—yet another genie in a bottle. A single vial of concentrate contains approximately 1 g of fibrinogen (i.e., equivalent to the amount of fibrinogen present in 5 units of either Cryo or FFP). Fibrinogen concentrate use to treat cardiac surgery bleeding is off-label (N.B. thromboembolic complications have been associated with its use) and it may take up to 20 minutes to solubilize this biologic depending on its temperature. Thawed Cryo is only good for 4 hours and must be stored at room temperature; it cannot be refrozen.

Finally, remember that any variety of coagulopathy can be exacerbated by hypothermia, electrolyte disturbances and/or acid–base imbalance, thus the use of fluid/patient warming systems and attention to blood gas/electrolyte analysis results is vital.

## TAKE HOME POINTS

- Effective treatment of cardiac surgical coagulopathy requires that both central laboratory coagulation/hematology tests (e.g., the aPTT, INR, fibrinogen concentration, Hb and platelet count) and POCT; for example, TEG/ROTEM are used to guide blood component/factor concentrate and protamine administration.
- Given its multiple shortcomings the ACT is not a good POCT to diagnose the specific etiology of cardiac surgical coagulopathy.
- Platelet count frequently underestimates need for platelet transfusion because CPB creates a functional thrombocytopenia.
- Post-CPB initiation, or “rescue” antifibrinolytic therapy, such as aminocaproic or tranexamic acid, is not recommended as a primary usage pattern since the efficacy and safety of this practice has not been established. “Rescue” therapy may be an option for patients with significant hemorrhage who did not receive pre-CPB treatment.
- Coagulopathy should be anticipated in patients that have undergone CPB times greater than 3 hours—so have hemostatic blood bank components in the operating room!
- Several antithrombotic and antiplatelet agents cannot be neutralized pharmacologically and require the administration of allogeneic blood products to

overcome their effects. Patients treated with these agents may benefit from the delay of elective cardiac surgery.

- Use of factor concentrates (e.g., balanced 4-factor prothrombin complex concentrates and rFVIIa) to treat cardiac surgery bleeding is off-label and should be reserved until after the administration of at least two rounds of banked hemostatic products have not slowed bleeding. Doses for this indication are not established and thus should be conservative (i.e., 20% to 30% of the package insert dose) as their use is associated with thromboembolic complications.
- Use of fibrinogen concentrate to treat cardiac surgical-related bleeding in hypofibrinogenemic patients is off-label but has been demonstrated to be effective in increasing the fibrinogen concentration and quelling hemorrhage. Consider its use when Cryo or FFP is not readily available. Goal fibrinogen level in bleeding cardiac surgical patients is >200 mg/dL.
- Note that any variety of coagulopathy can be exacerbated by hypothermia, electrolyte disturbances and/or acid–base imbalance, thus the use of fluid/patient warming systems and attention to blood gas/electrolyte analysis results **is imperative** in the management of any coagulopathy.

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# A Is for Aortic, C Is for Cannulation, B Is for … Be Careful!

Alexander S. Kuo, MS MD and Jason Zhensheng Qu, MD

A 64-year-old female with insulin-dependent diabetes, severe aortic atheromatous disease and peripheral vascular disease presents for coronary revascularization. Surgery is planned to include the use of cardiopulmonary bypass (CPB) with aortic cross clamp. Intraoperative pre-CPB transesophageal echocardiography (TEE) exam reveals a "mine field" of an ascending aorta with multiple mobile elements and protruding atheromatous plaques. The surgeon requests your help to find an appropriate site for insertion of the arterial perfusion cannula. What is your move in this situation?

**Answer:** An epiaortic scan will help better define the extent of atheromatous disease in the ascending aorta. The epiaortic scan did not suggest that it would be safe to place the cannula in the ascending aorta because the stroke risk from atheroma dislodgement would likely be too great. The surgeon begins to prepare for cannulation of the right axillary artery. Will your left radial arterial line be appropriate for systemic pressure monitoring? Yes, as long as the blood pressure in the left upper extremity is not substantially lower than the right. Minimizing stroke risk in this patient is a big challenge given his severe atheromatous disease and the planned use of an aortic cross clamp; iatrogenic aortic dissection should also be of major concern.

Cannulation for cardiac surgery does not often follow a straightforward formula. While the ascending aorta is the most common site of arterial cannulation for CPB, the presence of ascending aortic aneurysms, dissections, intramural hematoma, severe atherosclerosis or previous ascending aortic surgery may preclude safe cannulation in this region. **In severely atherosclerotic ascending aortas, the site of arterial cannula insertion and aortic cross clamping should be carefully chosen to avoid dislodging atheromas and minimize risk of embolization.**

Optimal selection of the aortic cannulation site is facilitated with epiaortic and transesophageal ultrasound assessment to avoid disrupting aortic atheromas. In cases of

aortic dissection, TEE can be used to identify and guide cannulation of the true lumen. TEE findings identifying the true lumen include: antegrade flow during systole, maximal expansion during systole, and being able to visualize the intact vascular intima. **Regardless of arterial cannulation site, CPB line pressures should be checked with a test infusion prior to initiation of full flow to reduce the risk of arterial dissection or expansion of existing dissection.** Alternative sites for arterial cannulation include: the femoral artery, axillary artery, innominate artery, common carotid artery, and cardiac apex. Each cannulation site has unique implications for perfusion techniques and hemodynamic monitoring.

## Femoral Artery Cannulation

Although having a higher dissection rate than the aorta, the femoral artery is the most common alternative site for CPB cannulation. This vessel is readily accessible and therefore often used for cannulation in emergent CPB or when the ascending aorta is not suitable. Upon initiation of CPB, the arterial blood flows retrograde through the aorta from the groin toward the aortic arch. In select emergent cases (e.g., massive pulmonary embolism), femoral cannulation can be accomplished under local anesthesia to avoid the potential hemodynamic collapse that may accompany induction of general anesthesia (related to the blunting of sympathetic outflow) and the initiation of positive pressure ventilation.

In cases of aortic dissection, the descending aorta and femoral artery are often involved. Retrograde perfusion via femoral cannulation may disrupt atheromatous plaques or elevate intima dissection flaps causing obstruction of branch vessels with consequent neurologic or visceral organ ischemia. In severely atherosclerotic vessels, perfusion from the femoral artery may also cause retrograde embolization from the atherosclerotic aortic wall. Commonly the right femoral artery is cannulated for CPB in patients with descending thoracic aortic dissections because it is more common for dissections to extend into the left femoral artery.

## Axillary Artery Cannulation

In comparison to the femoral artery, the axillary artery is usually less affected by atherosclerosis or dissection. Axillary artery cannulation minimizes the need to manipulate an atherosclerotic ascending aorta which may reduce the potential for atheroembolic sequelae. Further, since the arterial inflow is further away from the cerebral vessels and not directly aimed at them, cerebral embolic load may be decreased.

For an operation that requires prolonged deep hypothermic circulatory arrest (DHCA), it is necessary to have a cannulation strategy that promotes cerebral

protection. Right axillary artery cannulation can provide anterograde right common carotid artery perfusion in conjunction with innominate artery occlusion during DHCA (Fig. 230.1). Axillary artery cannulation for CPB can be either direct or via an end-to-side interposition graft. The use of right axillary artery cannulation may confound ipsilateral radial blood pressure monitoring. If the axillary artery is too small to accommodate full CPB flow, additional femoral or aortic artery cannulation is also needed to achieve target CPB flow.

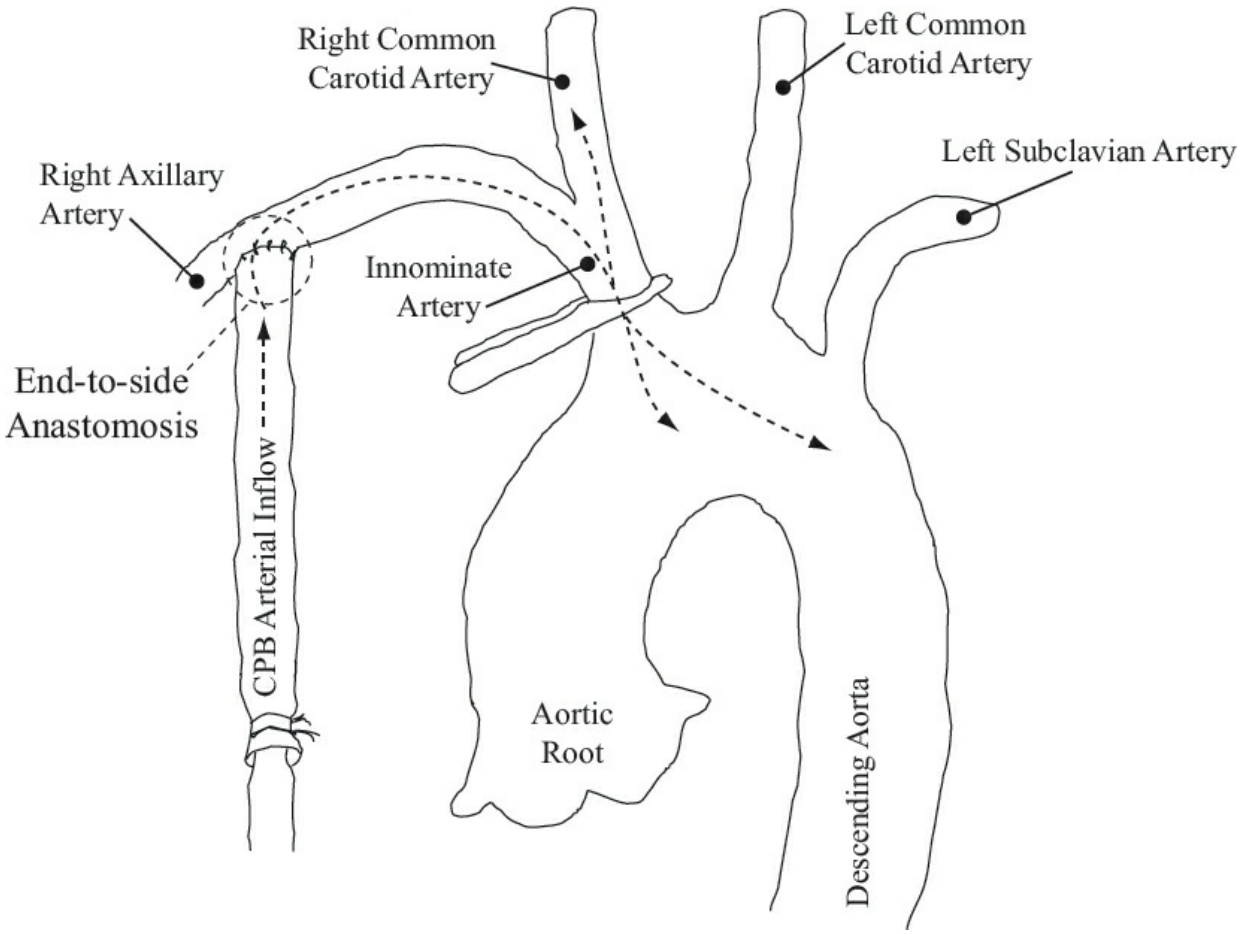


**Figure 230.1.** Right axillary artery cannulation with interpositional graft and antegrade selective cerebral perfusion. With the innominate artery clamp off, the CPB pump provides systemic blood flow via the interpositional graft through the axillary artery (dashed arrows). The arterial pressure recorded from right radial artery will be significantly higher than that of the left radial or femoral arteries. When the innominate artery is clamped, the CPB pump provides antegrade cerebral perfusion via right carotid artery (solid arrows).

The efficacy of antegrade or retrograde brain perfusion for neurologic protection during DHCA is controversial. Most authors agree that there is not enough evidence to support retrograde cerebral perfusion (perfusing the brain via superior vena cava with oxygenated blood) compared to anterograde cerebral perfusion or simply deep hypothermia only. In any cerebral protection strategy employed during DHCA, be sure

to use a cerebral oximeter as it can be very useful to determine regional cerebral oxygenation and may prompt changes in the protection strategy that can minimize the incidence of stroke.

## Innominate Artery Cannulation

This technique provides all the above-mentioned advantages of right axillary artery cannulation, but with greater simplicity since there is no need of an adjunctive incision. It is especially useful in emergency cases (e.g., acute type A dissection).

## Line Placement and Pressure Monitoring

The radial artery is the most common peripheral artery used to monitor systemic blood pressure during CPB. In the absence of significant arterial stenosis, the laterality of radial artery cannulation is not clinically significant. Patients should be screened for differential upper extremity blood pressures prior to CPB if radial, brachial, or axillary artery monitoring is used. However, when axillary or innominate arterial cannulation for CPB is planned, bilateral radial or single femoral arterial pressure measurement is recommended to more accurately assess true systemic perfusion pressure.

There are several techniques used to access the right axillary artery during CPB, such as end-to-side anastomosis or direct cannulation. Depending on the technique, the right radial artery pressure may be significantly higher or lower than aortic pressures due to the small caliber of the axillary artery, the close proximity to the perfuser, and the angle of the cannula/interposition graft. Therefore, it is crucial to have femoral or left radial artery pressures to reliably monitor systemic perfusion pressure on CPB. Hypoperfusion of the brain and other organs could occur if right radial artery pressure is depended upon for monitoring systemic blood pressure with an axillary cannulation strategy and use of a cerebral oximeter may be the only clue to the occurrence of this potentially devastating problem.

### TAKE HOME POINTS

- In severely atherosclerotic ascending aortas, the site of arterial cannula insertion and aortic cross clamping should be carefully chosen to avoid dislodging atheromas and minimize the risk of embolization.
- Regardless of arterial cannulation site, CPB line pressures should be checked with a test infusion prior to initiation of full flow to reduce the risk of arterial dissection or expansion of existing dissection.
- In select emergent cases (e.g., massive pulmonary embolism), femoral cannulation can be accomplished under local anesthesia to avoid the potential hemodynamic

collapse that may accompany induction of general anesthesia (related to the blunting of sympathetic outflow) and the initiation of positive pressure ventilation.

- Commonly the right femoral artery is cannulated for CPB in patients with descending thoracic aortic dissections because it is more common for dissections to extend into the left femoral artery.
- For an operation that requires prolonged DHCA, it is necessary to have a cannulation strategy that promotes cerebral protection. Right axillary artery cannulation can provide anterograde right common carotid artery perfusion in conjunction with innominate artery occlusion during DHCA.
- In any cerebral protection strategy employed during DHCA, be sure to use a cerebral oximeter as it can be very useful to determine regional cerebral oxygenation and may prompt changes in the protection strategy that can minimize the incidence of stroke.
- When axillary or innominate arterial cannulation for CPB is planned, bilateral radial or single femoral arterial pressure measurement is recommended to more accurately assess true systemic perfusion pressure.

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# Transesophageal Echocardiography in the Cardiac Surgery Suite—Strategies to Stay Out of Trouble

Robert W. Kyle, DO

Perioperative transesophageal echocardiography (TEE) use has become a standard of care for cardiac surgical patients in most centers. While strong outcome data on TEE use are still lacking (does TEE result in lower overall morbidity and mortality compared to patients treated without TEE?), perioperative decision making can be significantly impacted by TEE. One study showed that in a cardiac surgical population of roughly 12,500, intraoperative decision making was impacted overall by 9%. TEE use and its subsequent impact will likely continue to increase with the expansion of hybrid surgical techniques (transcutaneous aortic valve replacement or TAVR, for example) and the increasing age and frailty of the surgical patient population.

Like all forms of invasive monitoring, the use of TEE needs to be scrutinized to ensure that the **monitor itself** does not harm the patient. Fortunately, there are relatively few seriously adverse complications of TEE. Untoward events can include, but are not limited to, severe odynophagia, esophageal rupture, bleeding varices, bleeding ulcers, endotracheal tube dislodgement, and dental/oral trauma.

**Table 231.1 ■ Absolute and Relative Contraindications to Transesophageal Echocardiography**

| Relative Contraindications | Absolute Contraindications |
|---|---|
| History of radiation to neck and mediastinum | Perforated viscus |
| History of gastrointestinal surgery | Esophageal stricture |
| Recent upper GI bleed | Esophageal tumor |
| Barrett's esophagus | Esophageal perforation, laceration |

| | |
|---|---|
| History of dysphagia | Active upper gastrointestinal bleed |
| Resrictrion of neck mobility (severe cervical arthritis, atlantoaxial joint disease) | |
| Esophageal varices | |
| Coagulopathy, thrombocytopenia | |
| Active esophagitis | |
| Active peptic ulcer disease | |

The reported incidence of mortality related to TEE use is less than 0.02% and carries an overall incidence of complications of about 0.2% (with severe odynophagia and upper gastrointestinal bleeds being among the most common)—most would agree that these are numbers we can all live with! However, the literature on TEE complications sends a clear signal that our **older, female, and more frail patients** appear to be at significantly higher risk for injury related to TEE use.

**The key with TEE use is to focus on staying out of trouble-–not getting out of it**! TEE probes should not be placed in patients who have an absolute contraindication and clinicians have different ideas about which patients fall into this category. The 2010 American Society of Anesthesiology and Society of Cardiovascular Anesthesiology Task Force on TEE's Practice Guidelines for Perioperative TEE consider the following absolute contraindications for TEE: esophageal stricture, tracheoesophageal fistula, postesophageal surgery, and esophageal trauma. Other disease states all fall into the realm of relative risk assessment, meaning that the benefit of TEE to patient care should be carefully weighed against any potential harm. More recently published guidelines on absolute and relative contraindications are presented in Table 231.1. The bottom line on determining what a relative versus absolute contraindication is for TEE use is involves a thorough assessment of the patient being considered and a full, patient-specific risk/benefit analysis. With these guidelines for reference and an in-depth perioperative history and physical, one can appropriately employ TEE, minimize risk, and successfully avoid the malpractice attorneys. Table 231.2 lists general indications for TEE use.

In order to know if a patient has a contraindication to TEE, you must ask the patient about their medical history, as well as signs and symptoms pertinent to their comorbidities. Pertinent signs and symptoms include dysphagia, odynophagia, coffee-ground emesis or hematochezia, liver disease, history of varices or variceal banding, significant long-standing (especially untreated) GERD, and hiatal hernia.

When placing a TEE probe, get your focus on and follow these three basic guiding principles: (1) **NEVER** force the probe. If there is resistance, reevaluate your current approach and optimize the patient's position; (2) Use an adequate amount of sterile, water-based lubrication (note that many of the ultrasonic gels used for topical applications come with clearly labeled warnings—FOR EXTERNAL USE ONLY and thus should not be used for TEE); (3) Gently displace the mandible anteriorly while placing the probe to create an appropriate passage to the esophageal orifice. Laryngoscopy can be used effectively to assist in creating the necessary room to accommodate and place the TEE in more challenging placements. Be cognizant of the hemodynamic effects of placing the TEE probe and adjust anesthetic depth or analgesia accordingly. Lastly, applying mild anteflexion may assist the probe into the esophagus in certain patients by better approximating the anatomical angle of the pharynx. Care should be made, though, to have the probe in the neutral position when moving the probe in the upper and midesophagus.

**Table 231.2 ■ General Indications for Transesophageal Echocardiography**

1) Evaluation of cardiac and aortic structure and function in situations where the findings will alter management and TTE (transthoracic echocardiography) is non-diagnostic or TTE is deferred because there is a high probability that it will be non-diagnostic.
   a. Detailed evaluation of the abnormalities in structures that are typically in the far field such as the aorta and the left atrial appendage.
   b. Evaluation of prosthetic heart valves.
   c. Evaluation of paravalvular abscesses (both native and prosthetic valves).
   d. Patients on ventilators.
   e. Patients with chest wall injuries.
   f. Patients with body habitus preventing adequate TTE imaging.
   g. Patients unable to move into the left lateral decubitus position.
2) Intraoperative TEE
   a. All open heart (i.e., valvular) and thoracic aortic surgical procedures.
   b. Use in some or all coronary artery bypass graft surgeries.
   c. Noncardiac surgery when patients have known or suspected cardiovascular pathology which may impact outcomes (also known as "Rescue TEE" in acute clinical situations).

3) Guidance of transcatheter procedure
   a. Guiding management of catheter-based intracardiac procedures (including septal defect closure or atrial appendage obliteration, and transcatheter valve procedures).
4) Critically ill patients
   a. Patients in whom diagnostic information is not obtainable by TTE and this information is expected to alter management.

If your moves are spent and you are still unable to pass the probe, but feel that the surgery necessitates TEE, consider obtaining a surgical consult (i.e., evaluate the esophagus with an endoscope) and use of a pediatric TEE probe. Pediatric omniplane probes are of sufficient length (especially in women) and less likely to cause injury due to their small diameter. Another alternative to inserting a TEE probe may be to switch strategies and perform either epiaortic/epicardial (for cardiac cases) or transthoracic echocardiography (for cases not involving the thorax).

## TAKE HOME POINTS

- The key with TEE use is to focus on staying out of trouble—not getting out of it.
- Fortunately, the reported incidence of mortality related to TEE use is less than 0.02% and carries an overall incidence of complications of about 0.2% (with severe odynophagia and upper gastrointestinal bleeds being among the most common).
- Older, female, and more frail patients appear to be at significantly higher risk for injury related to TEE use.
- The bottom line on determining what a relative versus absolute contraindication is for TEE use is involves a thorough assessment of the patient being considered and a full, patient-specific risk/benefit analysis.
- When placing a TEE probe get your focus on and follow these three basic guiding principles:
  - **NEVER** force the probe.
  - Use an adequate amount of sterile, water-based lubrication (note that many of the ultrasonic gels used for topical applications come with clearly labeled warnings—FOR EXTERNAL USE ONLY and thus should not be used for TEE).
  - In general TEE probe placement is facilitated by mild anteflexion of the probe, gentle anterior mandible displacement, judicious use of a laryngoscope and in the most difficult placement possible the use of a smaller diameter pediatric TEE probe.

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# Myocardial Protection Strategies During Cardiopulmonary Bypass—Do Everything You Can but Realize That Some Ischemic Damage Is Inevitable

S. Michael Roberts, DO, Theodore J. Cios, MD MPH, and Dmitri Guvakov, MD

A 62-year-old male with advanced heart failure related to ischemic cardiomyopathy presented for an orthotopic heart transplant. Following successful separation from cardiopulmonary bypass (CPB) the aorta was injured to an extent that required return to CPB and rearrest of the new heart to repair the aorta. A medical student observing the case has some questions about "the whole cardioplegia thing."

## Why Do We Need to Protect the Heart?

**The most important thing to remember is that some myocardial damage is inevitable during CPB; our goal is to minimize its extent and hope that the majority of the insult is reversible over time**. Only a portion of the damage is due to ischemia; the majority of myocardial damage during CPB is due to reperfusion injury.

Reperfusion releases free radicals causing direct myocardial dysfunction, intracellular acidosis, edema, calcium overload, inflammatory cascade initiation, and complement activation. Normally functioning myocardium consumes 9 mL $O_2$/100 g/min. Emptying the heart decreases the myocardial work and the consumption to 5.5 mL $O_2$/100 g/min. Inducing asystole via cardioplegia further reduces this to 1.8 mL $O_2$/100 g/min, and cooling the still heart to 22°C reduces the basal consumption to 0.3 mL $O_2$/100 g/min. Unfortunately, fibrillation increases these values to 6.5 mL $O_2$/100 g/min at 37°C and 2.0 mL $O_2$/100 g/min at 22°C. Clearly a cold, empty, motionless heart would result in the lowest oxygen consumption and favor the best balance between supply and demand.

Key factors in minimizing myocardial damage are **avoiding ventricular fibrillation and ventricular distention during CPB** (especially during antegrade cardioplegia

delivery in patients with aortic insufficiency). Other factors, such as direct trauma from surgical manipulation, excessive inotropes, and coronary emboli (either plaque or air), can contribute. Even microscopic air emboli are associated with endothelial dysfunction. These ischemic events generally result in myocardial stunning—dysfunction that resolves within 48 to 72 hours. Excessive ischemia can result in more significant and lasting damage. As a secondary insult, reperfusion injury occurs when the aortic cross-clamp is removed. Understandably, our goals should be to maximize the oxygen supply–delivery balance during CPB and minimize the effects of reperfusion. **Effective myocardial protection is essential for successful cardiac surgery.**

## How Do We Protect the Heart? Cardioplegia!

The ideal cardioplegia solution would quickly arrest all areas of the heart, allow early return of function, and minimize the need for inotropes. The most common method of protecting the myocardium is through giving cold, potassium-rich (10 to 40 mEq/L) cardioplegia. Anterograde cardioplegia is delivered proximal to the aortic cross-clamp into the coronary ostia, whereas retrograde involves the placement of a coronary sinus catheter through a right atriotomy or via transesophageal echocardiography (TEE)-guided transjugular approach. **While administering retrograde cardioplegia, keep the coronary sinus pressures under 40 mm Hg, in contrast to 100 mm Hg with anterograde delivery, to avoid rupturing coronary venules and capillaries.**

High-risk patients appear to do better when given both anterograde and retrograde cardioplegia but, with that said, some clinicians favor the isolated use of just anterograde or retrograde cardioplegia. The myocardial protection literature is complex and previously conducted studies may no longer be applicable as CPB techniques evolve. The potassium-rich cardioplegia arrests the myocardium in diastole through the inactivation of sodium channels. The makeup of cardioplegia solution varies with manufacturer and institutional preferences. **Regardless of its delivery route (anterograde vs. retrograde) the goals of administering any cardioplegia solution are the same: reduce oxygen demand, calcium overload, myocardial edema, and provide an energy supply for the myocardium.**

## How Often Is the Cardioplegia Given?

Any exogenously administered inotropes should be discontinued upon initiation of CPB to decrease myocardial oxygen consumption. The timing of cardioplegia delivery depends on the type of solution. Traditional solutions require administration approximately every 20 minutes to maintain asystole and consistent temperature. New solutions have recently come to market which are more dilute, have less calcium, and contain lidocaine. The main advantage is that they can be administered as a single dose

for most pump runs. Other techniques involve delivery of cardioplegia that is almost all blood with addition of key electrolytes (e.g., potassium and magnesium); this technique is referred to as "microplegia" and is thought to minimize myocardial edema as less than 100 mL of crystalloid may be delivered during a long aortic cross-clamp time in contrast to several liters of crystalloid with other techniques.

## How Warm or How Cold Is the Cardioplegia Solution?

Cardioplegia can be delivered as warm (37°C), cold (9°C), or tepid (29°C). Cold solution may decrease oxygen consumption, but may cause cellular damage via fluidity, transmembrane gradients, and edema. Evidence supports tepid cardioplegia for balancing the reduction of myocardial metabolic demands and enhancing oxygen delivery while allowing prompt recovery of myocardial function. Other studies have demonstrated a clinical benefit with the use of warm cardioplegia (i.e., lower troponin levels and shorter duration of intubation and hospitalization). **No matter what cardioplegia solution is used, warm blood should be given through the cardioplegia pump prior to weaning from CPB to reverse the effect of cardioplegia and wash out the evil humors.**

## Should the Cardioplegia Be Mostly Crystalloid or Blood?

Cardioplegia can be given as crystalloid or mixed in variable ratios of blood to crystalloid to improve oxygen-carrying capacity and provide endogenous buffers. Some literature suggests that there is no significant difference in the reduction of perioperative myocardial infarction in the use of cold blood cardioplegia compared to cold crystalloid cardioplegia. The rate of return of spontaneous sinus rhythm, 30-day mortality, incidence of atrial fibrillation and stroke were not significantly different between the two groups. Other studies have shown that myocardial metabolism is better with blood cardioplegia but there is no improvement in myocardial damage or clinical outcome. While the use of microplegia (i.e., whole blood with concentrated electrolytes) may seem appealing, large randomized studies are needed to verify whether its use is superior to traditional cardioplegia.

## What Is the Deal With Hyperpolarizing Versus Depolarizing Cardioplegia Solutions?

Depolarizing cardioplegia is most often used for myocardial protection during CPB. The high concentration of potassium serves as a depolarizing agent. Intracellular sodium influx causes calcium to be released from the sarcoplasmic reticulum, causing myocardial injury. Newer agents induce asystole via opening potassium channels,

triggering hyperpolarization of the myocardium and inhibiting contraction and preserving energy. There is evidence to suggest hyperpolarizing solutions preserve coronary endothelial function better than depolarizing solutions but consensus has not been reached.

## Does Transesophageal Echocardiography Play a Role in Cardioplegia Delivery?

In today's cardiothoracic operating room, TEE can be considered a "standard" monitor. Using a modified midesophageal four-chamber view, the anesthesiologist can assist in confirming and documenting the placement of the retrograde coronary sinus catheter. Other views may also be helpful. Presence of a large coronary sinus could indicate a persistent left superior vena cava, rendering retrograde cardioplegia administration ineffective and redirecting the solution to the brain with the possibility of creating a watershed cerebral stroke. Difficulty placing a catheter may be due to the presence of a thebesian valve occluding the ostia of the coronary sinus. Color flow Doppler can be used to look for the flow of cardioplegia into the sinus and for antegrade flow down the left and right coronary arteries in the midesophageal aortic valve short axis view. For minimally invasive procedures, TEE is used to place the coronary sinus catheter via the internal jugular vein.

## Is There Anything Else We Can Do to Protect the Heart?

Ischemic preconditioning has long been recognized in reducing myocardial injury by protecting the heart from repeated ischemic events by endogenous mechanisms. Volatile anesthetics have been shown to produce a preconditioning effect and their use, when compared to intravenous anesthetics, have been shown to improve perioperative cardiac surgical clinical outcomes.

A similar theory of ischemic postconditioning suggests protection via a post-survival kinase mechanism. Administering opioids, bradykinin, magnesium, adenosine, and cyclosporine-A at reperfusion have all shown promising results in various investigations. Results of select studies are promising in decreasing postoperative troponin levels and inotrope requirements.

Another modality with beneficial results is the use of acute normovolemic hemodilution which is associated with decreases in serum biomarkers, inotrope requirements, and arrhythmias postoperatively by improving rheology for low-flow coronary collaterals and causing endogenous erythropoietin release. Erythropoietin causes endogenous nitric oxide release in the coronaries causing vasodilation and endothelial protection. Other myocardial protective techniques include the use of perioperative carvedilol, glucocorticoids, and nesiritide, all of which show promising

results for the future.

## TAKE HOME POINTS

- Some myocardial damage is inevitable during CPB; our goal is to minimize its extent and hope that the majority of the insult is reversible over time.
- Effective myocardial protection is critical for successful cardiac surgery.
- CPB-associated myocardial damage is due to ischemic insults and reperfusion injury.
- Regardless of its delivery route (anterograde vs. retrograde) the goals of administering any cardioplegia solution are the same: reduce oxygen demand, calcium overload, myocardial edema, and provide an energy supply for the myocardium.
- While administering retrograde cardioplegia, keep the coronary sinus pressures under 40 mm Hg, in contrast to 100 mm Hg with anterograde delivery, to avoid rupturing coronary venules and capillaries.
- Following the initiation of CPB, all exogenous inotropes should be discontinued.
- There is a lack of absolute consensus on which cardioplegia solution is clinically superior.
- Retrograde cardioplegia is useful in valve surgery and for patients with significant coronary artery disease and aortic insufficiency.
- TEE has an important role in verifying placement of coronary sinus catheters.
- Volatile anesthetics confer a protective preconditioning effect against ischemic damage.
- A warm, whole blood infusion is the best form of a "myocardial wake-up call" following cardioplegic arrest of the heart.

## Suggested Readings


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# The Heartbreak of Left-Sided Valvular Dysfunction

Jafer Ali, MD and Oran Kremen, MD

A 73-year-old female presents with a fractured right hip secondary to a mechanical fall. She is scheduled for urgent right total hip replacement under general anesthesia. She has been followed for many years with echocardiographs for a history of aortic stenosis (AS) but has not undergone corrective surgery. Her past medical history is also significant for diabetes mellitus type II, chronic obstructive pulmonary disease, and obesity. She notes being able to walk one to two city blocks before becoming winded. Upon physical examination she has a harsh, blowing IV/VI systolic ejection murmur that is loudest at the right sternal border and radiates up into both common carotid arteries. Her lungs are clear bilaterally. Chest film does suggest cardiomegaly but there is no appreciable pulmonary edema. There is time for an urgent transthoracic echocardiograph, but what would you do with that information? She needs the hip fixed urgently or she risks developing osteomyelitis and sepsis. What are your anesthetic goals for this patient? What are the biggest pitfalls that are associated with this valvular lesion?

The anesthetic management of patients with cardiac valvular disease may span all types of surgery and is not really that complicated in that it involves four basic questions:

) Which valve(s) is/are affected?
) Is the lesion stenotic, regurgitant, or mixed?
) What is the severity of the stenosis and/or regurgitation?
) What are the secondary signs and symptoms related to the valvular pathology?

Anesthesia providers do a good job of knowing how normal physiology may change under the influence of general anesthesia and surgical interventions. **When it comes to patients with valvular lesions, it is of paramount importance that the anesthesia provider has goals in mind with regard to the physiologic variables of preload, afterload, contractility, heart rate, and rhythm.** The good news is that these goals are

basically formulaic so you can either commit them to memory or save a table or reference paper in your phone or tablet for quick reference. This chapter will focus on left-sided cardiac valves.

## Need-to-Know Information for Aortic Valve Disease

### Aortic Stenosis

Normal aortic valve anatomy is three cusps and an aortic valve area (AVA) of 2.6 to 3.5 $cm^2$ but the important number to remember is **1.0 $cm^2$** because when the AVA drops to or below 1.0 $cm^2$ that is considered severe AS and can be either congenital or acquired disease. Congenital AS may include a unicuspid, bicuspid (most common), tricuspid, or quadricuspid valve. Calcification of a bicuspid aortic valve can lead to early-onset AS (i.e., late fifties or early sixties so it is unlikely our clinical vignette patient has a bicuspid aortic valve). AS may also be acquired by degenerative calcification, which is the most common cause in the developed world whereas rheumatic AS is more common worldwide and it frequently affects the mitral valve concurrently. The severity of AS is classified by aortic jet velocity (m/s), mean gradient (mm Hg), and AVA ($cm^2$). Be aware that a low cardiac index can underestimate the severity of AS and in some cases severe AS may present with a low gradient (e.g., an individual with normal left ventricular systolic function may have severe AS but, due to ventricular noncompliance secondary to hypertrophy, can have a low gradient.)

Associated findings in patients with AS include abnormalities of the aorta (i.e., aortic root dilation and increased risk of aortic dissection). These patients typically present with angina (most common presenting symptom), syncope, or congestive heart failure (i.e., resulting from ventricular noncompliance in the setting normal systolic function). As the AS worsens, the transvalvular gradient increases in most patients. This increased pressure gradient causes a compensatory concentric left ventricular hypertrophy which ultimately renders the ventricle preload dependent.

## Hemodynamic Goals for Aortic Stenosis—"Slow, Sinus, and Tight"

**Preload**—Normovolemia; decreased ventricular compliance that accompanies AS necessitates a higher end diastolic volume/pressure to allow for adequate preload augmentation. Consider preoperative volume loading with a goal of normovolemia and be aware that rapidly delivered volume loads can result in acute, diastolic congestive heart failure.

**Afterload**—Normal to high systemic vascular resistance (i.e., "tight") is desirable. Systemic and coronary perfusion pressure depends on maintenance of systemic blood

pressure and systemic vascular resistance—so use of alpha-1 agonists to vasoconstrict is strongly recommended, especially accompanying anesthesia induction when sympathectomy is pronounced.

**Contractility**—Avoid major cardiac depressants and remember these patients have normal to supranormal systolic function.

**Heart Rate**—Lower rate normal sinus rhythm heart rate is ideal (50 beats/min to 70 beats/min). Tachycardia limits diastolic filing time both in the left ventricle and the coronary arteries. Tachyarrhythmias will be poorly tolerated and should be electrically cardioverted if hemodynamically significant.

Additional Clinical Pearls for AS management:

- Attach external defibrillator pads to a patient prior to induction to be ready for a possible need for cardioversion.
- Strongly consider a preinduction arterial line and phenylephrine drip.
- Be cautious with vasodilators, especially nitroglycerin and nitroprusside as it can wreak havoc on preload and arterial pressure concurrently.
- Administer your anesthetic drugs slowly in smaller increments to allow time for some compensation from native physiology or if necessary to give you time to support the patient as needed with vasoconstrictors or volume administration to maintain organ perfusion.

## Aortic Insufficiency

Insufficiency (or regurgitation) is the failure of a valve to prevent backflow of blood. Causes of aortic insufficiency (AI) can be congenital or acquired. Congenital lesions include aortic valvular abnormalities and aortic root dilation (which can be associated with Marfan disease or other connective tissue disorders). Acquired etiologies include chronic hypertension, atherosclerosis, aortitis, aortic dissection, trauma, and aortic valve endocarditis. Severe acute AI can be life threatening and can lead to shortness of breath, pulmonary edema, and cardiovascular collapse. Acute AI may require urgent surgical treatment secondary to hemodynamic instability. Chronic AI may develop over the course of many years and patients may develop symptoms such as angina and fatigue after the onset of left ventricular dysfunction.

## Hemodynamic Goals for Aortic Insufficiency—"Fast, Full, and Forward"

**Preload**—Euvolemia with a preference toward being "full" and be cautious of drugs with significant venous dilatory effects as this may lead to further decreases in cardiac

output.

**Afterload**—Low normal as there is improved cardiac performance and forward flow with decreased systemic vascular resistance.

**Contractility**—Maintain contractility and avoid negative inotropes. Patients with chronic AI may develop eccentric left ventricular hypertrophy and/or dysfunction. Any inotropic decreases can be treated with beta-1/2 agonists (e.g., dobutamine) and inodilators (e.g., milrinone). These drugs have the perfect combination of peripheral vasodilation and inotropic support.

**Heart Rate**—Fast (goal in the range of 90 beats/min to 100 beats/min). Patients with a faster heart rate have decreased diastolic time during which the regurgitation is manifested. This will lead to a smaller regurgitant fraction and improved cardiac performance.

Additional Clinical Pearls for AI management:

- Many anesthetic drugs cause a drop in systemic vascular resistance and this can be very beneficial in patients with aortic regurgitation.
- Always remember that severe AI is an absolute contraindication for intra-aortic balloon pump placement (like shooting yourself in both feet!)
- The process of weaning from cardiopulmonary bypass can be more difficult than expected due to pre-existing left ventricular dysfunction and inadequate cardiac protection on CPB (difficult to deliver antegrade cardioplegia with AI). Keep inotropic agents ready to go!
- As with AS give your anesthetic drugs slowly as to allow native physiology to compensate or to permit administration of drugs to support physiology that maintains organ perfusion.

## Need-to-Know Information for Mitral Valve Disease

Good news is that as far as predictability the mitral valve is the valve most commonly affected with disease and is usually related to insufficiency (i.e., mitral stenosis [MS] accounts for less than 1% of cardiac diseases). Bad news is that when you come up against MS it can be the most challenging valvular pathology to manage during an anesthetic.

## Mitral Stenosis

MS is classically caused by rheumatic fever, which is rare in the United States, but may be seen more commonly in developing countries. Another common cause of MS is

mitral annular calcification. A normal mitral valve area is 4 to 6 $cm^2$ but the important number to remember is that severe MS is defined as a valve area less than 1$cm^2$ (just like severe AS). MS inhibits left ventricle filling and this process causes left atrial pressure to increase, which can lead to left atrial dilation, atrial fibrillation, pulmonary hypertension, congestive heart failure, and ultimately right-sided heart failure if the valvular dysfunction is not corrected.

## Hemodynamic Goals for Mitral Stenosis

**Preload**—Maintain preload and avoid hypovolemia.

**Afterload**—Maintain systemic vascular resistance and decrease pulmonary vascular resistance to maximize left heart filling (i.e., avoid light anesthesia, hypercapnia, hypoxia, acidosis, and hypothermia).

**Heart Rate**—Definitely avoid tachycardia! Slower heart rates allow for atrial emptying, but extreme bradycardia is dangerous given that cardiac output is fixed due to the stenotic mitral valve.

**Rhythm**—Maintain sinus rhythm to get the filling benefit of the atrial kick—this is a key point!

**Contractility**—Maintain contractility and be aware that chronic underfilling of the left ventricle may lead to a deconditioned state; inotropes may be needed. Also there may be right ventricular dysfunction in the setting of long-standing pulmonary hypertension, so don't blow off right heart assessment!

## Mitral Regurgitation

The most common cause of mitral regurgitation (MR) is mitral valve prolapse followed by functional MR. Mitral valve prolapse can be caused by damage to heart muscle after a myocardial infarction. Myocardial infarction may cause chordae tendineae and/or papillary muscle rupture resulting in acute MR that necessitates intra-aortic balloon pump placement or emergency surgery; more commonly myocardial infarction with associated (and unwelcome) ventricular dysfunction related to papillary muscle dysfunction/displacement is the cause of MR. Rheumatic disease and infection/endocarditis of the mitral valve can also cause valvular dysfunction. Conditions that cause dilation of the left heart, such as ischemic or nonischemic left heart failure, can cause the mitral valve annulus to stretch with resultant leaflet malcoaptation and regurgitation (also termed functional MR).

MR creates a state of left ventricular volume overload. Untreated, MR causes initial increases in left ventricular compliance, but progresses to left ventricular hypertrophy

as the heart must work harder to eject blood into systemic circulation as well as the regurgitant fraction back into the left atrium. As the left ventricle thickens, its compliance begins to decrease which results in diastolic dysfunction.

Be aware that following mitral valve replacement/repair, preload to the left ventricle suddenly decreases and the left ventricle can no longer pump into the low pressure "pop-off" left atrium. These physiologic changes can cause acute left heart failure and the need for inotropes.

## Hemodynamic Goals for Mitral Regurgitation

**Preload**—Slightly increased preload is the goal but fluid responsiveness needs to be titrated individually as the increased preload can worsen MR.

**Afterload**—Reduce systemic vascular resistance to decrease regurgitant fraction and improve cardiac output. Decrease pulmonary vascular resistance (i.e., avoid light anesthesia, hypercapnia, hypoxia, acidosis, and hypothermia and take note that the intra-aortic balloon pump can be very helpful in these situations).

**Heart Rate**—Aggressively avoid bradycardia as slow heart rates will cause increased left ventricular volume, reduced forward cardiac output, and increased regurgitant fraction. Normal to slightly elevated heart rate is preferred.

**Rhythm**—Sinus rhythm is ideal, but atrial fibrillation is common and usually physiologically compensated when chronic, acute atrial dysrhythmias may respond well to synchronized cardioversion.

**Contractility**—Maintain contractility and consider that inotropic support is frequently needed post mitral valve replacement.

### TAKE HOME POINTS

- When it comes to patients with valvular lesions, it is of paramount importance that the anesthesia provider has goals in mind with regard to the physiologic variables of preload, afterload, contractility, heart rate, and rhythm.
- For both aortic and mitral stenosis, the important number to remember is 1.0 $cm^2$ because when the valve area drops to or below 1.0 $cm^2$ that is considered severe stenosis.
- Be aware that a low cardiac index can underestimate the severity of AS and in some cases severe AS may present with a low gradient (e.g., an individual with normal left ventricular systolic function may have severe AS but, due to ventricular noncompliance secondary to hypertrophy, can present with a low gradient).

- Basic anesthetic-related hemodynamic goals for AS are normovolemia, slow to normal sinus rhythm (50 to 70 beats/min), and slightly elevated systemic vascular resistance (well achieved with low doses of alpha-agonists).
- Basic anesthetic-related goals for aortic regurgitation are euvolemia, faster heart rate (90 beats/min), and low normal systemic vascular resistance.
- Anesthetic-related goals for MS are euvolemia, normal systemic vascular resistance, decrease pulmonary vascular resistance to maximize left heart filling (i.e., avoid light anesthesia, hypercapnia, hypoxia, acidosis, and hypothermia), and avoid tachycardia as well as extreme bradycardia.
- Anesthetic-related hemodynamic goals for MR are slightly increased preload, normal to slightly elevated heart rate (70 to 90 beats/min), maintain sinus rhythm (but atrial fibrillation is common in these patients), and decreased systemic as well as pulmonary vascular resistance.

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# Anesthesia for the Descending Thoracic Aorta —Initiate Damage Control Measures

Eliot Ro, MD and Edwin G. Avery IV, MD

A 68-year-old male presents to the emergency ward complaining of acute onset of severe back pain. He has a past medical history of hypertension, hyperlipidemia, coronary artery disease, chronic obstructive pulmonary disease, and morbid obesity. His chest film reveals a widened mediastinum and just after completing computed tomography imaging he becomes unresponsive and develops pulseless electrical activity arrest. While the emergency ward team is resuscitating him the radiologist notes from his scan that contrast dye is extravasating from an aneurysm in the descending thoracic aorta(DTA). The surgical team is given a heads-up that he is being transported up to the operating room STAT while administering advanced cardiac life support measures. How are you going to use the little time you have to prepare for this patient? What are the most important aspects of this anesthetic?

DTA procedures present a huge anesthetic challenge. The general categories of aortic pathology affecting the DTA include: aneurysm, pseudoaneurysm, coarctation, aortic rupture, dissection, intramural hematoma, infection, and atherosclerotic disease (with or without penetrating ulcers). Successfully designing an effective anesthetic plan for these patients mandates a detailed knowledge of an individual's aortic pathology, the planned procedure and strategies to minimize the hit to various organs related to surgical manipulation of the aorta.

In some cases of DTA aneurysms and other pathologies, the repairs occur electively and are commonly addressed using endovascular stenting technologies that considerably reduce the complexity of the surgery. In other scenarios, such as the clinical vignette above, they present in an urgent or emergent fashion with little time to evaluate the serious comorbidities that frequently accompany aortic disease (e.g., coronary and cerebrovascular disease). Ideally, the anesthesiologist will review the details of all available imaging studies and create an anesthetic plan that focuses on providing protection and support for all bodily systems affected by the planned procedure. **In**

**emergent surgical procedures involving the DTA, it becomes a "damage control situation" with the goals of simultaneously ordering blood components, establishing robust intravenous access, invasive monitors, some degree of acceptable hemodynamics and amnesia; thus, recruiting additional anesthesia and/or surgical personnel is necessary so that preoperative preparation is carried out with optimal efficiency.**

## Monitoring for DTA Procedures

Successful anesthetic monitoring for DTA surgery considers that the nature of these procedures creates hemodynamic instability and multi-organ hypoperfusion. To partially circumvent the effects of interrupting blood flow with aortic cross-clamping the distal aorta is often perfused using a Gott shunt or partial left-heart bypass (left atrium to distal aorta, iliac, or femoral artery bypass with centrifugal pump assist). **Upper body arterial as well as femoral arterial blood pressure monitoring is therefore necessary to assess both proximal and distal arterial perfusion pressure relative to the aortic cross-clamp(s).** Distal aortic mean arterial pressure (MAP) is commonly maintained between 60 mm Hg and 70 mm Hg during the partial bypass period while proximal MAP is maintained at approximately 90 mm Hg. Near-infrared tissue oximetry monitoring of the frontal lobes as well as somatic monitoring of the quadriceps bilaterally may assist in fine-tuning individually appropriate MAP values above and below the cross-clamp, respectively. Be aware that partial left-heart bypass circuits do not routinely incorporate a heater/cooler exchange unit and therefore the risk of developing a profound hypothermia is greatly increased as heat is lost through the extracorporeal circuit. **Hypothermia increases the risk of coagulopathic hemorrhage and hyperglycemia (which may exacerbate ischemic injury to the brain, cord and/or heart) in these patients and thus patient warming systems (e.g., forced convective warm air blankets or hydrogel energy conduction pads) should routinely be used in these anesthetics**. Alternatively, a customized extracorporeal membrane oxygenator (ECMO) venous to arterial circuit could be employed that would accomplish the same result and allows for incorporation of a heater/cooler exchange device which obviates hypothermia issues.

**Invasive monitoring and central venous access are essential for DTA surgery**. Exercise caution in choosing a site for radial arterial cannulation because atherosclerosis is highly prevalent in these patients and severe subclavian or axillary artery plaquing can result in inaccurate hemodynamic data. Checking bilateral noninvasive cuff pressures can identify significant gradients between the upper extremities. Central venous access is useful to permit rapid volume and vasoactive medication administration as well as to monitor cardiac function and filling pressures

(e.g., by insertion of a pulmonary artery catheter). Alternatively, use of specialized arterial monitoring transducers can provide acceptable continuous indexes of cardiac output without pulmonary artery catheterization. Intraoperative transesophageal echocardiography (TEE) can also be useful for hemodynamic monitoring when the needed equipment and skillset are available.

Aortic cross-clamping acutely increases afterload on the left heart that may result in myocardial ischemia and/or acute left ventricular failure in susceptible patients. Careful monitoring for ischemic ECG changes and/or signs of acute left ventricular failure (e.g., an acute increase in the pulmonary capillary wedge pressure, drop in cardiac output or new wall motion abnormalities observed with TEE) during aortic cross-clamping is necessary. **Pharmacologic-based afterload reduction (e.g., administration of a short-acting dihydropyridine calcium channel blocker or nitric oxide donor) is often indicated during aortic cross-clamping**. Aortic cross-clamp removal can also be accompanied by hemodynamic instability (e.g., hypotension) related to an acute reduction in left ventricular afterload and to the release of lactic acid from ischemic tissue beds distal to the clamp if partial left-heart bypass is not employed. The transient increase in circulating lactic acid and potassium associated with cross-clamp removal can also instigate ventricular irritability or arrhythmias. Fluid loading and pharmacotherapy (e.g., administration of alpha-1 agonists and sodium bicarbonate) just prior to and after unclamping can be useful to quell the hemodynamic deterioration.

## DTA Surgery and Organ Ischemia/Protection

The temporary interruption of aortic blood flow associated with DTA surgery to allow for aortic interposition grafting places all distal organs (e.g., kidneys, bowels, spinal cord) at risk for ischemic injury and infarction. **Potential ischemic injury to the spinal cord is of paramount concern, thus the anesthetic plan is tailored to both monitor for and prevent such damage.** Protection of the spinal cord during DTA surgery is accomplished with maneuvers that promote blood flow to the cord. Suggested interventions include the preoperative insertion of a lumbar spinal drain, arterial pressure augmentation, neurophysiologic monitoring techniques, and pharmacologic support measures. Lumbar cerebral spinal fluid (CSF) drainage is employed to both prevent cord ischemia as well as a treatment for postoperative paraplegia resulting from DTA surgery (i.e., removing CSF to offset the swelling of the cord promotes lower intradural pressures and better perfusion). These lumbar catheters are managed without the use of a heparinized or pressurized transducer flush apparatus. CSF is permitted to drain if the lumbar CSF pressure exceeds 10 mm Hg. Care is taken to ensure a normal coagulation profile prior to catheter insertion and removal. Arterial pressure augmentation is achieved by maintaining a spinal cord perfusion pressure (MAP-–

intrathecal pressure) of at least 70 mm Hg which is accomplished by achieving an MAP of 80 mm Hg to 100 mm Hg.

Intraoperative neurophysiologic monitoring can reveal the acute development of spinal cord ischemia and is accomplished through the use of somatosensory-evoked potentials or motor-evoked potentials. Pharmacologic support measures include the intrathecal administration of preservative-free papaverine (in conjunction with lumbar CSF drainage) and the systemic administration of glucocorticoids, thiopental, mannitol, magnesium, calcium channel blockers, and naloxone. Supportive studies of these drugs in this clinical setting are difficult to interpret and no widely used standard pharmacologic regimen has been established to date. Intravenous naloxone given at 1 µg/kg/hr has been demonstrated to be associated with improved neurologic outcomes (including reversal of paraplegic symptoms) in this clinical setting.

## DTA Anatomical Considerations

Left thoracotomy or a thoracoabdominal incision is the most common surgical incision used for exposure of the DTA. These surgical approaches often necessitate single-lung ventilation, most often of the right lung. Options for single-lung ventilation include lung retraction, insertion of a left bronchial blocker, or the use of a double lumen endobronchial tube (DLT) (i.e., commonly a left DLT is employed). The DLT permits pulmonary maneuvers such as the ability to suction the airways and apply continuous positive airway pressure which may be obviated with the use of a blocker. However, its use may require transition to a single-lumen endotracheal tube at the end of the procedure with the inherent risks after a major surgery.

## DTA Analgesia

**Consideration of postoperative analgesia is of major concern in this clinical setting because of the painful nature of a thoracotomy.** The intra- and postoperative use of thoracic epidural analgesia can provide excellent pain control and permit early extubation to allow for the prompt assessment of neurologic function (e.g., rule out paraplegia related to spinal cord ischemia); care must be taken to ensure normal function of the coagulation cascade for both insertion and removal of the catheter to prevent bleeding-related neurologic complications. Emergent procedures obviate the preoperative insertion of an epidural catheter but postoperative insertion remains an option in most cases.

### TAKE HOME POINTS

- In emergent surgical procedures involving the DTA, it becomes a “damage control

situation" with the goals of simultaneously ordering blood components, establishing robust intravenous access, invasive monitors, some degree of acceptable hemodynamics and amnesia; thus, recruiting additional anesthesia and/or surgical personnel is necessary so that preoperative preparation is carried out with optimal efficiency.

- Invasive monitoring and central venous access are essential for DTA surgery. Exercise caution in choosing a site for radial arterial cannulation because atherosclerosis is highly prevalent in these patients and severe subclavian, or axillary artery plaquing can result in inaccurate hemodynamic data. Both upper- and lower-extremity arterial monitoring are often required.
- Potential ischemic injury to the spinal cord is of paramount concern and thus the anesthetic plan is tailored to both prevent such damage and to monitor for it.
- When DTA surgery involves the use of partial left-heart bypass, femoral arterial blood pressure monitoring is necessary to assess distal arterial perfusion pressure.
- Hypothermia increases the risk of coagulopathic hemorrhage and hyperglycemia (which may exacerbate ischemic injury to the brain, cord and/or heart) in these patients and thus patient/fluid warming systems are routinely used.
- Pharmacologic-based afterload reduction (e.g., administration of short-acting vasodilators including clevidipine, sodium nitroprusside, and nitroglycerin) is often indicated during aortic cross-clamping to prevent acute left-heart failure.
- The transient increase in circulating lactic acid and potassium associated with aortic cross-clamp removal can instigate ventricular arrhythmias.
- Fluid loading and pharmacotherapy (e.g., administration of alpha-1 agonists and sodium bicarbonate) just prior to aortic unclamping can be useful to quell the associated hemodynamic deterioration.
- Lumbar CSF drainage is employed to prevent/treat spinal cord ischemia. These catheters are managed without the use of a heparinized or pressurized transducer flush apparatus.
- Consideration of the use of postoperative thoracic epidural analgesia is important in this clinical setting because of the painful nature of a thoracotomy.

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# Buckle Your Seat Belt: Taking Care of the Patient With Ascending Aortic Dissection

Rachel E. Schlesinger, MD and Kathleen Cho, MD

A 72-year-old female arrives to the emergency ward gripping her chest complaining of intense tearing pain; she is also wailing about unbearable burning pain in her left leg (like it's on fire). Medical history is significant for poorly controlled hypertension, emphysema, and hyperlipidemia. Vital signs are notable for blood pressure (BP)—left arm: 188/124 mm Hg, right arm: 125/110 mm Hg; pulse 124/minute; respirations 25/minute. Physical examination is remarkable for confusion, diminished breath sounds bilaterally, and a loud holodiastolic murmur. Pulses are unequal with the right radial grossly weaker than the left and left pedal pulse weaker than the right. She has a 14-gauge venous catheter in the left forearm. Electrocardiogram reveals sinus tachycardia with inferior lead ST-segment elevations, likely related to the dissection in the aortic root partially obstructing coronary blood flow in the proximal right coronary artery. Chest film demonstrates widening of the mediastinum and a computed tomography (CT) scan confirms an ascending aortic dissection extending from the aortic root to the iliac bifurcation (we call that a stem-to-stern dissection in cardiac OR lingo). Next, you get paged to the operating room to assist with management of this challenging patient, so strap in and hold on because you're in for a ride! What is the next most appropriate management step?

ANSWER: First, establish arterial monitoring in the left radial artery (i.e., higher BP on the left so the right side is probably lower because the aortic dissection (AD) involves the innominate and right subclavian arteries thus yielding a falsely lower central BP), then reduce the aortic shear stress and systolic BP (i.e., to approximately 110 mm Hg) by first initiating a short-acting intravenous β-blocker (i.e., esmolol) and next start an intravenous systemic arterial selective vasodilator (i.e., clevidipine) infusion. Order four units of blood and get a quick transthoracic (or transesophageal) echocardiogram to assess for cardiac tamponade and to determine the mechanism of her aortic insufficiency (AI) which the holodiastolic murmur tipped you off to. Get extra help in the room

because time is of the essence in these cases, and even when you do your job just right, the patient can still have a bad outcome.

Dissections of the ascending aorta, representing 60% to 70% of all ADs, are life-threatening emergencies that involve a tear of the intimal wall of the aorta creating a false channel that may contain blood flow or intramural hematoma. AD are commonly spontaneous but can be related to trauma (e.g., motor vehicle accident when the chest wall strikes the steering wheel). **AD of the ascending aorta is a true medical emergency and carries a mortality rate of 1% to 2% per hour in the first 48 hours, following initial onset of symptoms.** (We suggest quoting this mortality statistic if you are stopped by local law enforcement on the way to the hospital to treat a patient with an AD as it often results in a sirens blaring/blue lights flashing escort to the hospital.) Reported surgical mortality varies from 3% to 24% and is highest with dissections at the level of the aortic arch.

It is common for the aorta to be aneurysmal in the area where it dissects. Aneurysm formation is clinically occult over a period of years and is most commonly associated with uncontrolled hypertension and a genetic defect resulting in the production a dysfunctional fibrillin protein located in the aortic wall. Another possible mechanism for AD is rupture of the vasa vasorum, creating an intramural hematoma and propagation of the dissection; this variant lacks an intimal tear but has the same mortality as an AD with a tear. The areas of highest mechanical stress are the ascending aorta and the area just distal to the left subclavian artery. **Due to the shear stress created by hypertension and pulsatile perfusion, the dissection flap can continue to dissect in its proximal or distal extent (often in a spiral manner) and potentially compromise blood flow to multiple vital organs.** It is very common to hear from our surgical colleagues that the tear in the aortic intima is located just above the ostia of the right coronary artery, another area of high mechanical stress in the aorta. In any case, identifying the location of the tear is not an anesthesia-related priority.

Risk factors for AD include male gender, chronic and/or uncontrolled hypertension, age >60 years, connective tissue disorders (e.g., Marfan syndrome), uni-, bi-, or quadricuspid aortic valve, aortic aneurysm, pregnancy, toxins (e.g., cocaine use), trauma, and postaortotomy. Two classification systems are in use to detail the extent of an AD that include the Stanford and DeBakey systems (see Table 235.1).

**The most common presentation of ascending AD is chest pain described as either ripping, tearing, sharp, stabbing, or pressure-like and there may be pulse deficits in the extremities, suggesting limb ischemia or systemic hypoperfusion.** Note that in our vignette patient she was also complaining of severe left leg pain that was likely due to AD-related lower limb ischemia. **AD resulting in cardiac tamponade (i.e., commonly from aortic root rupture or more commonly blood**

**weeping through the dissected aorta into the transverse pericardial sinus) may produce jugular venous elevation, systemic hypotension, syncope, stroke, and cardiovascular collapse. Note that extension of the AD into the head vessels can result in a range of neurologic symptoms from mild confusion to frank stroke and obtundation. In most cases if there is a true rupture of the aorta into the pericardial space via the transverse sinus it will result in acute and often irreversible cardiac arrest.** If the dissection causes severe AI, signs of congestive heart failure (e.g., pulmonary edema) may be present.

**Table 235.1 ■ Classification Systems for Aortic Dissection**

| Classification System | Type | Description |
|---|---|---|
| Stanford | A | Involves the ascending aorta |
| Stanford | B | Involves the descending aorta |
| DeBakey | I | Involves the entire aorta |
| DeBakey | II | Involves only the ascending aorta |
| DeBakey | III | Involves only the descending aorta |

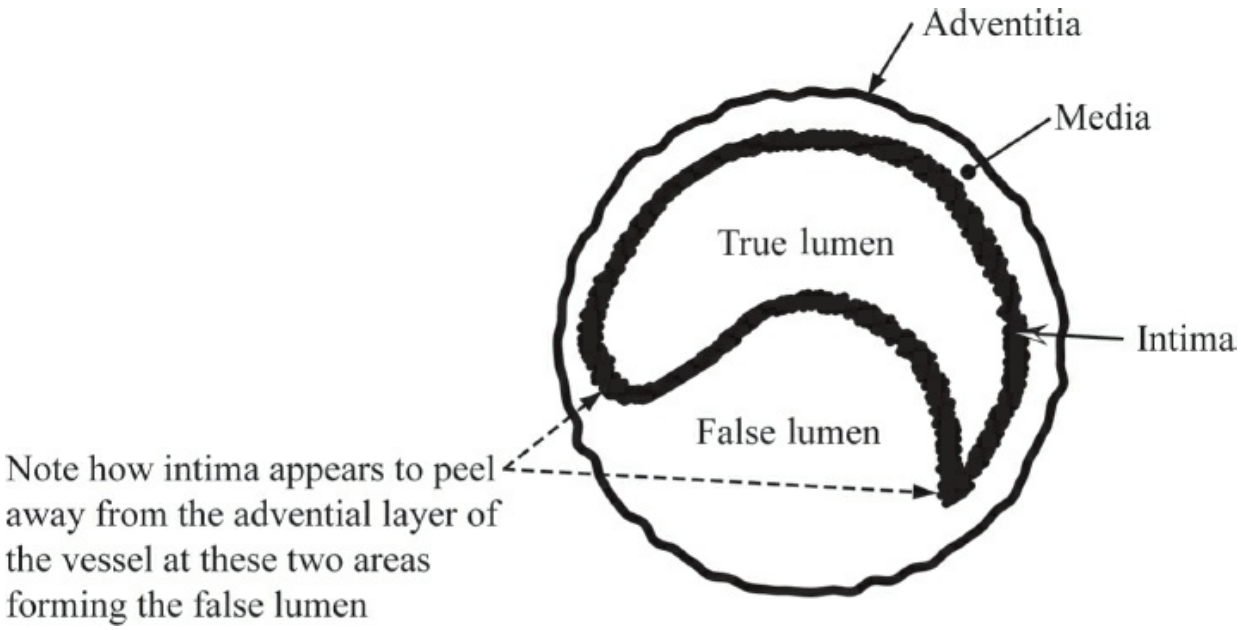


**Figure 235.1.** Line art drawing of aortic short axis as imaged with transesophageal echocardiography in aortic dissection.

**The degree of AI related to AD can vary from none all the way up to severe and**

**really depends on how badly the AD has undermined the function of the aortic valve.** Additional respiratory symptoms may include hoarseness due to compression of the recurrent laryngeal nerve, dysphagia, and stridor.

Diagnosis of ascending AD is commonly made by CT, aortic angiography, magnetic resonance imaging with angiography (most sensitive and specific), or transesophageal echocardiography (TEE). TEE is particularly useful as it allows one to rule out cardiac tamponade, determine mechanism/severity of AI, better characterize the extent of the dissection, and assess for proximal coronary artery involvement plus related wall motion abnormalities. Intraoperatively, TEE can help identify both the true and false aortic lumens, which will facilitate the arterial cannulation required for the initiation of cardiopulmonary bypass (CPB) (Fig. 235.1). **Any attempt to perform a preoperative diagnostic TEE must be made in conjunction with an experienced anesthesiologist because inadequate sedation and blunting of sympathetic autonomic outflow could result in immediate aortic rupture with unrecoverable hemodynamic collapse.**

Complications associated with ascending AD are listed in Table 235.2. The high degree of morbidity and mortality is usually related to involvement of the coronary ostia, dissection into the aortic root causing severe AI, and proximal dissection causing cardiac tamponade. Acute medical management is directed at control of systemic BP to reduce the shear stress or change in pressure over time ($\Delta P/\Delta t$) transmitted to the aortic wall. **Control of hemodynamics for AD is initially accomplished with a bolus of esmolol (i.e., 20 to 50 mg IV) and an infusion (25 to 300 mcg/kg/min) (this reduces the shear stress on the aortic wall) followed by initiation of a clevidipine or nicardipine (dihydropyridine calcium channel blockers are preferred here due to their arterial selectivity note that clevidipine and nicardipine have the same mechanism of action but clevidipine has an approximately 1 minute half-life and nicardipine has a 12- to 14-hour half-life) which will help limit extension of the dissection.** Although there has not been any pressure range proven to be best, 100 to 110 mm Hg systolic is the generally accepted goal. This pressure will likely maintain adequate organ perfusion while minimizing risk of aortic rupture.

**Table 235.2 ■ Complications of Acute Ascending Aortic Dissection (N = 513)**

| Complication | Percentage of Occurrence (%) |
|---|---|
| All neurologic deficits | 18 |
| Coma/altered consciousness | 14 |

| | |
|---|---|
| Myocardial ischemia/infarction | 4 |
| Acute renal failure | 6.2 |
| Hypotension | 26 |
| Cardiac tamponade | 17 |
| Mortality | 30 |

Adapted from Bossone E, Rampoldi V, Nienaber CA, et al. Usefulness of pulse deficit to predict in-hospital complications and mortality in patients with acute type A aortic dissection. Am J Cariol. 2002;89(7):851–855. Copyright © 2002 Excerpta Medica Inc. With permission.

Anesthetic management is directed at establishing both arterial and venous access and includes multiple large-bore intravenous catheters on blood warmers, a rapid infusion device, central venous access (i.e., permits monitoring of central filling pressures, cardiac index, mixed venous oxygenation as well as a delivery route for potent vasoactives). At least one arterial line must be placed depending on the surgical plan for arterial CPB cannulation. **Always be thoughtful about where you place your arterial monitoring catheter because the surgeon may cannulate an upstream arterial site that will make your observed BP inaccurate (i.e., lower than the actual central systemic BP). Pre-induction arterial monitoring is a standard of care.** Ultrasonic examination of the carotid arteries prior to central line placement can reveal vessel location and whether the dissection has extended into the neck. Such involvement is common with ascending AD, but flow obstruction–related carotid dissection is not common and portends increased mortality. **Have at least four units of cross-matched red blood cells available in the operating room before the procedure begins.**

**Necessary monitoring and adjuncts include standard American Society of Anesthesia monitors and use of cerebral oximetry is strongly suggested** as corrective surgery for AD very commonly involves deep hypothermic circulatory arrest which is best managed with this technology. During the period of circulatory arrest the cerebral oximeter functions much like a sand-filled hourglass as one can literally observe a slow deterioration of the cerebral saturation percentage over a period of just minutes as the cold, unperfused brain extracts the remaining oxygen from the hemoglobin in the brain's microcirculation. For surgeons that configure a unilateral selective anterograde perfusion setup, the cerebral oximeter can verify adequate perfusion and oxygenation of both sides of the brain. Unilaterally observed desaturation on the contralateral side of the brain during selective anterograde perfusion can alert clinicians to the absence of a complete circle of Willis and the potential need for insertion of a second anterograde cannula into the head vessels (i.e., most commonly the left common carotid artery). Further, **insertion of a Foley catheter (with temperature-monitoring capability), orogastric tube, and temperature of the shell and core are considered**

**standard of care.**

High-dose narcotic is a preferred induction method due to hemodynamic instability frequently observed in these patients but be careful as bradycardia in the setting of severe AI can result in cardiovascular collapse. **Induction of general anesthesia for patients with AD must always prioritize prevention of hypertension.** If securing the airway necessitates rapid sequence intubation, then esmolol and/or clevidipine boluses can be used to treat/prevent the hypertensive response to laryngoscopy. Clevidipine is preferred over nitroprusside as it is an ultra-short acting, arterial selective, lacks toxic metabolites (in contrast to cyanide-laced nitroprusside) and does not depend upon renal or hepatic function for its metabolism. Place the TEE probe after induction and perform a complete TEE examination with special attention to the extent of the dissection and degree/mechanism of AI.

If the dissection has caused a significant degree of cardiac tamponade, the transition to positive-pressure ventilation during the induction of general anesthesia can be deleterious for right heart filling and result in cardiovascular collapse. Maintain cardiac filling pressures with intravenous volume administration and a short inspiratory-to-expiratory ratio to maximize right heart filling. If pericardial tamponade is diagnosed or suspected, femoral cannulation for CPB under local anesthesia should be considered, followed by induction and immediate sternotomy. **Decompression of cardiac tamponade prior to bypass may cause rebound hypertension, resulting in aortic rupture and a tremendous increase in mortality risk.** (For every AD-related problem we know how to anticipate and fix, an acute ascending AD knows how to throw two more right back at us so turn your internal vigilance dial to "combat mode.") If femoral cannulation for CPB cannot be instituted under local anesthesia prior to inducing general anesthesia, then a careful induction with the gradual transition to assisted and, finally, positive pressure ventilation should be performed to minimize the risk of cardiovascular collapse. Such cases have the entire shooting match ready to go (e.g., low room temperature, the surgeon scrubbed, patient prepped and draped, ice bags made up to place on the head, perfusionists ready to go on bypass). If one is unsure about the magnitude of a pericardial effusion or the presence of pericardial tamponade, then a quick pre-induction transthoracic echocardiogram is strongly indicated to rule out a surprise hemodynamic collapse on induction. Support of hemodynamics during anesthesia induction of an AD patient with vasoconstrictors and/or inotropes is risky and can result in aortic rupture if there is an unintended overshoot. **The bottom line with induction of an AD patient is that the cardiac surgical, perfusion, and OR nursing teams should all be in the room and ready to go prior to anesthesia induction.**

Finally, TEE is useful to assess the adequacy of repair post-CPB including

restoration or augmentation of flow within the true aortic lumen, assessment of aortic valve repair/replacement, and evaluation of cardiac function. Cerebral oximetry can alert one to the presence of compromised cerebral blood flow post-CPB. Alternatively, the common carotid arteries can be directly assessed with a surface ultrasound probe via color Doppler interrogation to confirm that bilateral blood flow is present. **Following confirmation of a successful surgical repair, the anesthesia team should be prepared to both evaluate (e.g., via thromboelastography and core laboratory hematology/special coagulation studies) and aggressively treat coagulopathic hemorrhage.** The cold temperatures used to preserve organ function during deep hypothermic circulatory arrest commonly result in both platelet dysfunction and sequestration in the sinusoidal organs (i.e., the liver and spleen); thus it is standard to have platelets in the operating room before bypass separation.

## TAKE HOME POINTS

- AD of the ascending aorta is a true medical emergency and carries a mortality rate of 1% to 2% per hour in the first 48 hours, following initial onset of symptoms.
- Ascending AD and intramural hematoma both carry the same risk of mortality.
- Due to the shear stress created by hypertension and pulsatile perfusion, the dissection flap can continue to dissect in its proximal or distal extent (often in a spiral manner) and potentially compromise blood flow to multiple vital organs.
- The most common presentation of ascending AD is chest pain described as either ripping, tearing, sharp, stabbing, or pressure-like, and there may be pulse deficits in the extremities, suggesting limb ischemia or systemic hypoperfusion.
- AD resulting in cardiac tamponade (i.e., commonly from aortic root rupture or more commonly blood weeping through the dissected aorta into the transverse pericardial sinus) may produce jugular venous elevation, systemic hypotension, syncope, stroke, and cardiovascular collapse.
- Extension of the AD into the head vessels can result in a range of neurologic symptoms from mild confusion to frank stroke and obtundation.
- In most cases if there is a true rupture of the aorta into the pericardial space via the transverse sinus it will result in acute and often irreversible cardiac arrest.
- Any attempt to perform a preoperative diagnostic TEE must be made in conjunction with an experienced anesthesiologist because inadequate sedation and blunting of sympathetic autonomic outflow could result in immediate aortic rupture with unrecoverable hemodynamic collapse.
- Acute medical management of AD includes control of hemodynamics initially accomplished with a bolus of esmolol (i.e., 20 to 50 mg IV) and an infusion (25 to 300 mcg/kg/min) followed by initiation of a clevidipine or nicardipine

(dihydropyridine calcium channel blockers are preferred here due to their arterial selectivity note that clevidipine and nicardipine have the same mechanism of action but clevidipine has an approximately 1 minute half-life and nicardipine has a 12- to 14-hour half-life) which will help limit extension of the dissection.

- A systolic pressure of 100 to 110 mm Hg is the generally accepted goal.
- Have at least four units of cross-matched red blood cells available in the operating room before the procedure begins.
- Always be thoughtful about where you place your arterial monitoring catheter because the surgeon may cannulate an upstream arterial site that will make your observed BP inaccurate (i.e., lower than the actual central systemic BP). Pre-induction arterial monitoring is a standard of care.
- Induction of anesthesia for patients with AD must always prioritize prevention of hypertension. The short half-lives of esmolol and clevidipine make them ideal for BP control in these patients.
- Necessary monitoring and adjuncts include standard American Society of Anesthesia monitors and use of cerebral oximetry is strongly suggested.
- Insertion of a Foley catheter (with temperature monitoring capability), orogastric tube, and temperature of the shell and core are considered standard of care.
- Depending on the distal extent of the dissection, circulatory arrest may be required to perform an adequate surgical repair; neuroprotection is of paramount concern in cases requiring deep hypothermic circulatory arrest.
- If the dissection has caused cardiac tamponade, the transition to positive-pressure ventilation during the induction of anesthesia can be deleterious for right heart filling and result in cardiovascular collapse.
- Decompression of cardiac tamponade prior to the bypass may cause rebound hypertension, resulting in aortic rupture and an increased mortality risk.
- The bottom line with induction of an AD patient is that the cardiac surgical, perfusion and OR nursing teams should all be in the room and ready to go prior to anesthesia induction.
- Following confirmation of a successful surgical repair, the anesthesia team should be prepared to both evaluate (e.g., via thromboelastography, core hematology/special coagulation labs) and aggressively treat coagulopathic hemorrhage.

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# Rolling in the Deep Hypothermic Circulatory Arrest

Michael G. Fitzsimons, MD and Etienne J. Couture, MD FRCPC

A 38-year-old male with a history of Marfan disease presents with a dilated aortic root (65 mm), ascending aorta (60 mm), aortic arch (57 mm), descending aorta (43 mm) and mild aortic insufficiency. He is scheduled for a valve-sparing aortic root replacement, complete arch replacement, reimplantation of the arch vessels, and "elephant trunk procedure" to the distal aorta. His surgeon is planning on addressing the descending aorta at a future date. The surgeon notes that the procedure will be performed under deep hypothermic circulatory arrest (DHCA) that he believes will take less than 60 minutes. Bilateral radial arterial lines are placed along with two large-bore peripheral intravenous catheters. Near infrared spectroscopy (NIRS) is placed on the forehead for cerebral oximetry monitoring along with processed electroencephalogram (pEEG) monitoring. Baseline regional cerebral oxygen saturation ($rSO_2$) reads 77% on the right and 76% on the left. General anesthesia is induced with propofol, fentanyl, and rocuronium. A pulmonary artery catheter is placed via the right internal jugular vein. Transesophageal echocardiography (TEE) is utilized and a nasopharyngeal temperature probe is placed before systemic anticoagulation. The patient is cooled to a nasopharyngeal temperature of 18°C, cooling occurs for another 45 minutes while the surgeon performs portions of the aortic root reconstruction. Cerebral oximetry shows an $rSO_2$ of 90% on the right and 91% on the left. The surgeon completes the distal arch elephant trunk anastomosis, arch replacement, and arch vessels reimplantation under DHCA. Individual selective cerebral perfusion is performed on the arch vessels. DHCA ends after 46 minutes and systemic perfusion is resumed while the surgeon completes the root replacement and final anastomosis. The patient is successfully weaned from cardiopulmonary bypass (CPB). TEE demonstrates absence of significant aortic insufficiency or stenosis. The patient is brought to the intensive care unit, is extubated and makes a complete recovery.

DHCA is a surgical technique where the body is cooled to 18°C. This profound hypothermia reduces the cerebral metabolic rate of oxygen consumption ($CMRO_2$) as well as systemic tissue oxygen consumption for the entire body. Once the temperature measures in the nasopharynx reaches 18°C, the body is generally cooled for an additional period of time to achieve a uniform temperature. Circulation from the CPB is then stopped and blood is drained into the CPB venous reservoir. The absence of flow allows the surgeon to remove the aortic cross clamp to facilitate surgery in locations where a cross clamp interferes. Distal aorta and aortic arch work is completed then CPB is resumed. DHCA may also be utilized for pulmonary thromboendarterectomy, surgery involving descending aorta, excision of renal cell carcinoma that has extended in to the right atrium and certain cerebral aneurysm clipping procedures.

## Mechanisms of Benefits of DHCA

The brain has a high $CMRO_2$ and is very sensitive to lack of oxygen. This is largely related to a limited supply of high-energy phosphates and glucose unlike other organs such as the liver or muscles. Cerebral injury occurs due to anaerobic glycolysis and entry of calcium into brain cells activating enzymes. DHCA reduces oxygen consumption significantly which increases the safe time that the brain can go without blood flow. $CMRO_2$ decreases approximately 5% to 7% for every 1°C below 37°C. When the body reaches a temperature of 18°C, metabolism is less than 25% that at normal body temperature. Other potential benefits include inhibition of caspases, reduction of toxic free radicals, reduction of inflammation, and maintenance of microvascular integrity. Several physical, pharmacologic, and surgical adjunctive techniques have been suggested to enhance the degree of protection as well as the duration of DHCA to facilitate longer procedures.

## Direct Application of Ice to the Head

Many will utilize direct application of ice from initiation of cooling until resumption of circulation and rewarming. The thought is that ice will facilitate additional cooling and prevent passive rewarming from the room. The thickness and density of the skull prevents any additional benefit to that provided by full-body cooling from CPB. The operating room temperature is usually decreased below 18°C which would eliminate any temperature gradient between the patient and the room. No human randomized studies have conclusively demonstrated advantages to external application of ice during DHCA. Care must be taken to avoid thermal injury to the eyes, ears, and other tissue if direct application of ice is utilized.

## Pharmacologic Adjuncts

Several single pharmacologic agents and combinations of medications have been suggested to augment the safety of DHCA. The steroid methylprednisolone has been utilized to reduce the inflammatory effects of DHCA including edema, free radical formation, and lipid peroxidation. Barbiturates act by reducing $CMRO_2$, free fatty acids, free radicals, cerebral edema, and seizure activity and are associated with burst suppression. Magnesium is a cerebral vasodilator. Lidocaine may improve short-term cognitive outcome. Mannitol is proposed to scavenge free radicals and reduce cerebral edema. **No pharmacologic agents have been demonstrated to reduce cerebral injury alone or in combination with others.**

## Blood Gas Management

There are two means to manage blood gas during DHCA, (1) pH-STAT and (2) alpha (α)-STAT.

The pH-STAT technique focuses on maintaining a pH of 7.40 and $PaCO_2$ of 40 mm Hg. Changing body temperature results in the perfusionist needing to add $CO_2$ to the circuit resulting in a respiratory acidosis. The respiratory acidosis results in an increase in cerebral vasodilation and an increased cerebral blood flow (CBF). The increase in CBF theoretically results in more rapid and uniform cooling of the brain, but at the risk of increases in cerebral embolic events due to higher flows.

The α-STAT technique focuses on preserving cerebral autoregulation by achieving a normal pH and $PaCO_2$ at 37°C and respiratory alkalosis results with reductions in CBF. No $CO_2$ is added. CBF is lower and the risk of emboli may be lower. The risk though is that cooling may not be uniform.

**No study has clearly demonstrated one blood gas management technique to be superior to another.** The pH-STAT approach (respiratory acidosis and increased CBF) during the cooling period may improve cerebral cooling while use of α-STAT (respiratory alkalosis and cerebral vasoconstriction) during warming may reduce embolic events yet preserve cerebral autoregulation and coupling of blood flow to $CMRO_2$.

## Selective Cerebral Perfusion

The brain is a highly metabolically active organ and highly vulnerable to any period of ischemia. Selective cerebral perfusion involves the delivery of blood and oxygen to the brain during the period that the rest of the body is subject to arrest and deprived of blood flow. Selective cerebral perfusion has been shown to prolong the period of systemic DHCA so that critical work on the aortic arch can be completed. A general

downside of these techniques is the addition of additional equipment or blood flow into the field.

**Retrograde cerebral perfusion** (RCP) involves perfusion of the brain through the venous system via the superior vena cava. Blood is pumped from the circuit at a rate of approximately 200 to 300 mL/min to a measured central venous pressure of 15 to 20 mm Hg. The mechanism of potential benefit of his technique is unclear. RCP may "flush" the cerebral vasculature of air and debris that accumulated during surgery. RCP may also provide additional cooling. This technique is becoming less popular.

**Antegrade cerebral perfusion** (ACP) can be hemispheric through the right axillary, subclavian or innominate artery. It can also be bihemispheric by adding an antegrade perfusion cannula to the left common carotid artery. There is no consensus for the perfusion pressure or flow however, blood flow is generally maintained between 5 to 20 mL/kg/min according to uni- or bilateral cerebral perfusion. Pressure is generally measured via the right radial arterial catheter and should be between 40 to 70 mm Hg. Higher pressure ACP may appear appealing but has been associated with increased CBF, intracranial pressure, higher post-CPB $CMRO_2$ and poorer neurologic recovery. Blood gases are often managed with a pH-STAT technique. ACP is more popular than RCP and permits longer periods of DHCA.

## Temperature Management During Rewarming

Rewarming involves resumption of systemic flow and increasing the patient's body temperature from 18°C to a temperature at which the problems associated with hypothermia are minimized without causing injury associated with hyperthermia in the vulnerable brain. Reperfusion will generally be initiated at 18°C for 5 minutes before beginning the rewarming process. The gradient between the warming inlet water temperature and the venous blood should be 10°C or less to avoid excessive rapid rewarming of the brain. The pH-STAT (respiratory acidosis and increased CBF) technique may be used until the brain temperature reaches 28°C then an α-STAT technique (respiratory alkalosis, preservation of auto-regulation) may be used to potentially reduce emboli-associated injury. A nasopharyngeal temperature of >36°C and a bladder temperature of >35°C but less than 37°C is adequate to initiate weaning from CPB. Inflow temperatures in excess of 37°C may result in cerebral hyperthermia and injury.

## Monitoring Cerebral Protection During DHCA

Since $CMRO_2$ is reduced significantly with hypothermia, the temperature of the brain must be followed accurately. The jugular bulb temperature is the most accurate reflector of brain temperature during DHCA but is difficult to access. The nasopharynx

temperature is most commonly utilized and is more accurate than measurement in the bladder or oropharynx. The probe should be placed gently in the naris before systemic anticoagulation for CPB to avoid trauma which may result in bleeding.

NIRS is a noninvasive means to assess cerebral oximetry through $rSO_2$. Within the brain 70% to 80% of the blood is venous (deoxygenated) and 20% to 30% is arterial (oxygenated). Differences in oxygen saturations between arterial (≈100%) and venous (≈ 60–70%) blood result in an average calculated $rSO_2$ of 60% to 70%. This reflects the balance between oxygen supply and demand. NIRS is a means to continuously monitor $rSO_2$. Decreases in $rSO_2$ may be correlated with postoperative neurologic dysfunction such as stroke, cognitive dysfunction, and delirium but it is unclear whether interventions such as increased perfusion pressure or maintenance of a high hematocrit improve outcomes. It is unclear what $rSO_2$ below which cerebral injury will occur. Drops in $rSO_2$ below 75% of the patient's baseline may result in cerebral injury.

Electrical brain activity can be monitored using traditional electroencephalographic (EEG) or pEEG monitoring. During cooling, change in electrical activity can be appreciated and during DHCA, electrical silence can be documented. It can also serve as a brain ischemia monitor while reduced cerebral electrical activity can be associated with hypoperfusion related to reduced CPB flows or hypotension. It can also serve to detect epileptiform activity which can also be caused by ischemia. Limitation of cerebral oximetry using NIRS and EEG resides in the inability to monitor activity of deeper structures such as hippocampus and basal nuclei that are highly vulnerable to ischemia.

## Additional Monitoring

Hypothermia induces resistance to insulin and hyperglycemia is generally seen during the cooling part. Conversely, insulin perfusion must be adjusted during rewarming to avoid hypoglycemia. Hyperglycemia has been shown to increase morbidity and mortality in cardiac surgical patients with and without diabetes. The Society of Thoracic Surgeons recommends that glucose levels be maintained below 180 mg/dL in the perioperative period.

### TAKE HOME POINTS

- Gradual systemic cooling to a body temperature of 18°C should occur when DHCA is chosen as a technique for cerebral protection.
- The use of topical application of ice during cooling and DHCA has not been demonstrated to provide any additional benefit to DHCA. If utilized, protection of

tissue against thermal injury is critical.

- No single pharmacologic agent or group of agents has been demonstrated to be beneficial during DHCA.
- Use of a pH-STAT technique during cooling results in a respiratory acidosis and increased uniform cerebral cooling associated with cerebral vasodilation.
- Use of an α-STAT technique during DHCA (if antegrade perfusion utilized) and during warming may reduce the risk of cerebral embolic events.
- Retrograde or antegrade cerebral perfusion may increase the safe period if DHCA is likely to last more than 20 minutes.
- During rewarming, inflow temperature should never exceed 37°C. A pH-STAT technique may be utilized until 28°C is reached then α-STAT. The temperature gradient between the inlet water temperature and venous blood temperature should be ≤10°C.
- Decreases in $rSO_2$ may be associated with postoperative neurologic decline such as stroke, cognitive dysfunction, and delirium but it is unclear whether interventions to increase $rSO_2$ improve these outcomes.

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# Anesthesia for Left Ventricular Assist Device Surgery: Essentials to Bear in Mind

Raymond G. Graber, MD and Daniel I. Asher, MD

A 57-year-old man with idiopathic cardiomyopathy and end-stage heart failure presents for elective left ventricular assist device (LVAD) destination therapy. Left ventricular (LV) ejection fraction is estimated to be less than 15%; right ventricular (RV) systolic function is moderately depressed. He has a biventricular implantable cardioverter/defibrillator (ICD). His congestive heart failure symptoms are medically well-managed, but he still has some pulmonary edema, significant pulmonary hypertension, mildly impaired renal function, and hepatic congestion despite being on milrinone and clevidipine infusions. What is the anesthetic plan for this patient? Do you stop his infusions? What is the invasive monitoring plan? What induction/anesthesia maintenance drugs will you use? Is the pre-cardiopulmonary bypass (CPB) and/or post-CPB transesophageal echocardiography examination (TEE) important? Are you concerned about post-CPB bleeding in this elective, "virgin chest" patient? What is the risk of right heart failure? Will you plan to extubate in the operating room?

Anesthesia for ventricular assist device (VAD) implantation surgeries can be very challenging. Let us consider our patient in this clinical vignette—where do we start when putting together the anesthetic plan for a patient like this? We will be tackling all these issues head on because ignoring even one of them can mean a disaster in the operating room and/or the intensive care unit.

## Introduction to Ventricular Assist Devices

Short-term VADs are implanted to provide support for a period of days to weeks in conditions that are presumably reversible (e.g., viral cardiomyopathies, acute cardiogenic shock, acute right heart failure after LVAD placement). Thus, these are placed as a "bridge to recovery" (the patient gets better, device is removed) or as a "bridge to decision" (patient doesn't get better, so patient is either converted to a long-

term device or decision made to withdraw support). Since these are placed for short-term indications, the pump is external to the body. For LV support, an inflow cannula is placed in the left atrium (LA) or apex of the LV, and blood is then returned via an outflow cannula into the ascending aorta. For RV support, an inflow cannula is placed in the right atrium or apex of the RV, and blood is then returned via an outflow cannula into the pulmonary artery.

Longer-term VADs are implanted as a "bridge to transplantation" in patients that are listed for cardiac transplantation but are failing conventional supportive therapy, or as permanent devices in patients who are not transplant candidates, which is known as "destination therapy." These pumps are implanted internally. In general, an inflow cannula is placed in the apex of the LV, and blood is then routed via a pump into an outflow graft which is sewn onto the ascending aorta. The pump is connected via a cable (that exits through the upper abdominal wall) to an external controller unit.

## Preoperative Concerns

Some important areas of focus during the preop evaluation:

- Review preoperative right heart cardiac catheterization and echocardiography data prior to taking these patients to the OR. You know the LV is going to be bad, but how about the RV?
- How is the function of the liver and kidneys? Have they been impaired by the combination of low flow and venous congestion?
- What is the status of the coagulation system? Liver production of clotting factors may be impaired. Many patients are on chronic coumadin or other anticoagulant therapy. This information may help guide what clotting factors should be ready and on hold at the time of surgery.
- Does the patient have an ICD and/or pacemaker? The ICD will need to be shut off prior to surgery, and the pacemaker may need to be re-programmed.
- Is the patient on inotropic support? Many patients are on dobutamine, milrinone, or vasodilator therapy when they present for surgery.
- Make sure appropriate blood products are on order for surgery. There should be 6 units of packed red cells in the room at the start of the case. The type of clotting factors ordered will to a certain extent depend on the preop clotting status. However, usually at least 6 units fresh frozen plasma and 10 units of platelets, are placed on hold, and need to be in room when you come off pump. Finally, cryoprecipitate may also be necessary if preoperative fibrinogen level is low. We generally prefer to keep fibrinogen level over 200 mg/dL when we are off pump and trying to dry up.

## Invasive Monitoring

Standard American Society of Anesthesia monitors are supplemented with an arterial line, pulmonary artery (PA) catheter, and TEE.

An arterial line is placed pre-induction. At our center, brachial arterial lines are frequently utilized to minimize post-CPB waveform damping issues. However, radial or femoral sites are also acceptable. You need to know where your surgeon is going to arterially cannulate for CPB. Don't place a right arm arterial line if the surgeon is going to cannulate the right axillary artery!

A pulmonary artery catheter may be placed prior to or after induction. Use ultrasound to scan the planned internal jugular (IJ) site prior to skin prep. These patients may have had multiple IJ sticks in the past, and may have thrombosed veins or other abnormal anatomy. A 9F introducer or a double lumen (9F/12 Ga) introducer is placed first, then the PA catheter is floated. Some centers utilize continuous cardiac output/mixed venous oxygen capable PA catheters to continuously assess adequacy of oxygen delivery. The PA catheter will help guide your inotropic and vasodilator choices.

TEE is invaluable in managing these patients, and will be discussed further later.

## Careful Induction and Maintenance

If the patient has been on inotropic support, it is maintained. If not on support, it is frequently helpful to start a low dose of inotrope (dopamine or epinephrine) to support heart function and blood pressure through the induction period. If a patient presents on a vasodilator (like sodium nitroprusside or clevidipine), these are turned off prior to induction, to avoid bottoming out the blood pressure.

Most of these patients will not tolerate lying flat, so anesthetic induction may have to be initiated with the patient in a head-up position. Most anesthesiologists will want to avoid significant vasodilation or cardiac depression, so will induce with etomidate in conjunction with moderate doses of fentanyl and midazolam. The idea is to minimize the sympathectomy as there is really very little, if any, cardiac reserve in VAD patients. Remember that these patients may have a prolonged induction time due to slow circulation. Low doses of inhalation agent can be added as tolerated.

Maintenance anesthesia is usually accomplished with a balanced technique of inhalational anesthetic, narcotic, benzodiazepines, and muscle relaxants.

## Other Management Issues

- Baseline coagulation labs should be drawn: CBC, PT/TT, INR, fibrinogen. At our center we also use thromboelastogram (TEG) to help guide administration of clotting factors.
- Good IV access is required. For example, two large-bore peripheral lines and double lumen (9F/12 Ga) introducer. At least two lines should be warmed for administration

of fluids and clotting factors.

- Tranexamic acid or ε-aminocaproic acid (Amicar®) is administered to reduce bleeding and blood product requirements.
- Hypotension can be multifactorial, but is frequently related to the use of angiotensin-converting enzyme (ACE) inhibitors, angiotensin receptor blockers, and milrinone. The vasodilatation induced by these agents can exacerbate anesthetic-induced vasodilatation. A vasoconstrictor such as vasopressin or norepinephrine may be needed if the SVR remains excessively low. Vasopressin has less effect on pulmonary vascular resistance, so is frequently used first. Methylene blue (1.5 to 2 mg/kg) is also sometimes used to treat refractory vasoplegia.

## Pre-CPB TEE Evaluation

Pre-pump, a complete TEE examination is performed. There are some specific areas of focus in LVAD patients:

- Is a patent foramen ovale (PFO) or ventricular septal defect (VSD) present? After LVAD initiation and LV decompression, the pressure gradient across the septa will increase, tending to cause or exacerbate right-to-left shunts if a PFO or VSD is not surgically closed.
- Is there significant aortic insufficiency (AI)? When AI is present, LVAD flow into the ascending aorta will circle back into the LV. A small amount of preop AI may become much more significant post LVAD activation as the pressure gradient across the aortic valve increases. Significant AI will need to be dealt with surgically—valve replacement or valve closure may be required.
- RV function is assessed. A failing right heart may require increased support, either with inotropes, nitric oxide, or RVAD. Worsening tricuspid regurgitation is an indicator of RV dilatation.
- The aorta is assessed for calcification, plaque, or dilation in order to assess the aortic graft site.
- The LV and LA are examined for thrombus, particularly at the apex of the LV where the LVAD inflow cannula is inserted.

## During CPB

CPB is managed as with any type of cardiac pump case. Vasopressors may be needed for blood pressure support in patients chronically on vasodilators. One should use this time wisely, to prepare for coming off CPB. All clotting factors and platelets should be prepared and in the room prior to termination of CPB. If nitric oxide is planned, it is hooked up to the anesthesia circuit during this time in preparation for coming off bypass. Inotropic support drugs should all be ready to go.

When getting close to coming off CPB, start the planned inotropic meds to support right heart function. Frequently, epinephrine and milrinone are used in combination.

Also, TEE should be used to confirm adequate deairing of the heart. Air has a tendency to make its way down the right coronary artery—leading to RV dysfunction. If this does occur, the systemic pressure should be raised to at least 80 to 90 mm Hg to drive the air bubbles through the coronary circulation. This should be followed by a recovery period while still on bypass.

## Separation From Bypass

When a patient is weaned off pump with an LVAD in place, the focus is on adequately volume loading the patient and monitoring the right heart to make sure it is tolerating the load. (More on that later!) After successful separation from CPB, you must be able to multitask, and deal with reversing protamine, managing underlying coagulopathy, maintaining euvolemia, keeping the patient warm, and correcting any metabolic derangements. Obtain frequent arterial blood gases to monitor for issues with potassium, glucose, metabolic acidosis, and adequacy of ventilation.

## Post-CPB TEE Evaluation

The post-CPB TEE examination focuses on the following:

- Assess the position and orientation (toward the mitral valve) of the LV apex inflow cannula. If obstruction is present, turbulent inflow will be seen, along with high velocity flows (>1.5 m/sec). However, some devices which lie directly adjacent to the LV apex will generate noise when Doppler is pointed at that location, and this precludes the ability to measure velocity.
- The outflow graft flow into the ascending aorta can frequently be assessed. If obstruction is present, turbulent flow may be seen, or high velocity flows (>2.0 m/sec) may be seen.
- RV size and function and the severity of tricuspid regurgitation are monitored.
- Assess the size of the LA and LV. If the LA and LV are noted to be too small, there may be inadequate RV preload or right heart failure. Treatment may include adding volume, temporarily cutting back on LVAD flow rate, or increasing right heart support. If the LV collapses, catastrophic air entrainment around the inflow cannula can occur.
- Keep an eye on the ventricular septum. If it deviates significantly in either direction, something needs to be addressed!
- The aortic valve should be reexamined to look for worsening of preexisting AI. Also reexamine the septa for shunts.

## Right Heart Support

When an LVAD is placed, preservation of RV function becomes a major priority. The right heart may fail in up to 20% of patients. Therefore, we always administer some kind of RV support when coming off CPB. The degree of support necessary will depend on the degree of underlying right heart dysfunction and the severity of pulmonary hypertension. We generally will start a beta agonist such as epinephrine prior to coming off CPB, and then also consider whether to add in milrinone +/− inhaled nitric oxide. Some centers use inhaled epoprostenol (Flolan®) as an alternative to nitric oxide.

We monitor the right heart in several ways. The CVP and PA pressures give us an indication of preload and afterload. The RV can be seen on the surgical field. TEE is used to monitor size and function of the RV, and to assess severity of tricuspid regurgitation. A failing right heart must be promptly addressed (e.g., increasing epinephrine dose, adding milrinone, ensuring that oxygenation and ventilation are adequate). In maybe 5% of cases, short-term RV assist device support may be required.

## Extubation Timing

**Intraoperative extubation is pretty much never a good idea for a VAD operation.** The idea is to support cardiac physiology and let the body get used to the weird new spinning do-dad that the surgeon just buried in the chest! In order to get extubated, the patient must be warm, not bleeding, not metabolically deranged, off nitric oxide, on reasonable levels of inotropic support, and hemodynamically stable. That takes time, and that means the patient is going to the ICU intubated.

### TAKE HOME POINTS

- LVAD patients are extremely ill, and are at risk for crashing on induction. These patients must be aggressively supported and monitored—with the goal being getting safely on bypass.
- Pre-CPB and post-CPB TEE is extremely important in the care of these patients.
- After CPB, the major areas of attention are preserving RV function, monitoring the LV/LVAD combination, and getting the patient dried up so you can get the patient out of the OR.

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# Off-Pump Coronary Artery Grafting Is Like Working on an Engine (While It Is Still Running)

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A 58-year-old female attorney presents with triple vessel coronary disease and elective coronary revascularization was planned. The left ventricular ejection fraction (LVEF) is 40% by echocardiogram. Preoperative imaging studies reveal a heavily calcified thoracic aorta (a.k.a. porcelain aorta). The patient's past medical history is notable for hypertension (HTN), Type II diabetes mellitus (DM), obesity, a 45 pack-year smoking history and intermittent claudication. In addition, she underwent left carotid endarterectomy (CEA) 5 years ago when she suffered a transient ischemic attack (TIA); recent blood tests have revealed mild renal insufficiency and elevated HbA1c. The surgeon plans an off-pump coronary artery bypass (OPCAB) surgery.

The patient is very fearful of stroke risk as an uncle of hers recently had one when undergoing coronary surgery. She asks you during her preoperative assessment what the risks and benefits of OPCAB versus conventional coronary surgery are.

OPCAB is a good option for this patient, given possible contraindications for aortic cannulation of the porcelain aorta. Her preoperative comorbidities suggest she certainly has increased stroke risk, especially if the procedure will involve aortic manipulation.

## Background

OPCAB has been practiced for many decades and following development of improved stabilization systems reached the height of its use in 2004. OPCAB is technically demanding both for anesthesiologists as well as surgeons and there is NO PUMP BREAK for the anesthesiologist! In contrast to the United States, OPCAB is practiced more frequently in other countries (e.g., Japan, China, India, Brazil). When conducted by experienced teams OPCAB is clinically as safe and effective as on-pump surgery with no difference in costs.

## Who Best Qualifies for OPCAB?

OPCAB patient selection depends upon multiple factors: patient's comorbidities as well as the number and location of vessels to be revascularized. For example, intramyocardial vessels are technically more difficult to graft during OPCAB surgery.

Relative contraindications of OPCAB include:

- Poor quality target vessels (intramyocardial vessels, diffusely diseased vessels, calcified coronary vessels)
- Cardiomegaly/congestive heart failure
- Critical left main disease
- Small distal targets
- Recent or current acute MI
- Poor left ventricular function (LVEF <35%)

## OPCAB Is Associated With Outcomes That Are Better or Worse or Equivocal Depending on the Specific Outcome in Question

### Better Outcomes Associated With OPCAB

**Stroke:** Systematic reviews of OPCAB do not show a benefit related to neurologic outcome; however, OPCAB may offer risk reduction of neurologic complications in patients with a significant carotid artery disease and a history of previous stroke. Consistent with these findings, use of newer technologies that obviate aortic clamping are reported to be associated with less stroke.

**Renal failure:** Systematic reviews of OPCAB literature did not reveal reduced renal complications; however, some published studies have demonstrated reduced risk of postoperative renal injury related to OPCAB. However, in end-stage renal failure patients, there was no benefit-related OPCAB versus conventional CABG.

**Systemic inflammation:** There is only limited evidence to show that OPCAB reduces systemic inflammation compared with on-pump surgery.

**Perioperative arrhythmia:** New-onset arrhythmias affect up to 60% of postcardiac surgical patients with atrial fibrillation (AF) being the most common. A systematic literature review does suggest a reduced risk of postoperative AF in patients undergoing OPCAB.

**Coagulopathy and bleeding:** OPCAB has been reported to provide less bleeding, higher platelet levels/function, decreased fibrinolysis as well as reduced bleeding and need for allogenic blood transfusion.

**Cardiogenic shock:** OPCAB has been reported to be associated with a reduced frequency of perioperative cardiogenic shock.

## Worse Outcomes Associated With OPCAB

**Mortality:** A number of studies find OPCAB to be associated with significantly increased mortality compared with on-pump surgery.

**Multivessel coronary artery disease and severe lesions in the circumflex territory:** OPCAB resulted in a higher incidence of cardiac events at 5-year follow-up.

## Equivocal Outcomes Associated with OPCAB

**Length of ICU Stay and Total Postoperative In-hospital Stay**

**Postoperative Myocardial Infarction**

**Long-term Outcome (1 year postcoronary surgery):** Primary composite outcome (rate of repeat coronary revascularization, quality of life, or neurocognitive function).

**Advanced Age:** In patients above 60 years old, there was no difference in long-term (5-year) outcome between OPCAB and on-pump surgery.

## Surgical Technique

Median sternotomy permits the best access to all coronary sites as well as the left internal mammary artery and thus remains the standard approach for OPCAB. Alternative approaches include the following: right mini-thoracotomy (good to access the right internal mammary artery and graft the right coronary), posterolateral thoracotomy (good to access the circumflex artery and obtuse marginal vessels), and subxiphoid approach (good to access the gastroepiploic artery for right coronary or posterior descending artery anastomosis).

KEEP YOUR EYES ON THE SURGICAL FIELD because severe hypotension and myocardial ischemia can be caused by surgical manipulation to access lateral wall vessels and posterior vessels can distort atrioventricular valves, by elevation and rotation of the heart. Atrial size and pressure may increase with concurrent low ventricular volume and pressure, requiring higher filling pressure to preserve cardiac output.

## Don’t Lose Sight of the Basics of Anesthetic Management for OPCAB Cases

In addition to a full preoperative assessment, OPCAB patients should be evaluated thoroughly regarding cardiac status, including the number and site of vessels to be revascularized, the type of lesion, a preoperative echocardiogram to check cardiac function and the presence of any valvular abnormality or septal defect. Remember that technology isn’t always your friend as surgical manipulations, for example the use of anastomosis stabilization devices, compress the heart and reduce stroke volume, thus

close hemodynamic monitoring and communication with the surgeons is needed. The daily mantra of anesthetic goals for these cases includes the following: maintenance of hemodynamic stability, normothermia, early detection and prompt management of myocardial ischemia, provision of adequate postoperative analgesia, rapid emergence, early extubation, and early patient mobilization for appropriate candidates. You have to know them, you have to understand them, and you should say them to yourself and your team every day while you are walking over to the OR.

## Monitoring

Optimal monitoring for OPCAB usually is considered to be standard anesthetic monitors plus transesophageal echocardiography (TEE). Note that the electrocardiogram (ECG) diagnosis of myocardial ischemia can be challenging as a result of the frequent axis shifts of the heart that accompany repositioning. Similarly, TEE detection of myocardial ischemia can be challenging depending on the position of the heart. TEE is also useful for the detection of patent foramen ovale (PFO), as high right atrial pressures are created during cardiac manipulations, and an undiagnosed PFO can cause right to left intracardiac shunting. Patient warming systems, for example forced convective air warming blanket or hydrogel energy conduction pads, as well as warmed intravenous fluids should be routinely used because there is no-rewarming help from the bypass pump with OPCAB. The use of a cerebral oximeter can be an early indicator of reduced cardiac output related to heart repositioning or ischemia.

## Lines and Access

Arterial catheterization, large-bore peripheral intravenous (IV) access (14G or 16G), and central venous access, either a triple lumen catheter or pulmonary artery (PA) catheter, are standard for OPCAB. Pacing PA catheters can allow atrial or ventricular pacing if needed. Surface electrode pads for defibrillation and cardioversion are standard for OPCAB.

## Anesthetics

Any of the available IV induction agents can be titrated in depending upon the patient's hemodynamic status. High-dose narcotic-based anesthetics are not advisable when early extubation is the goal. Fentanyl (5 to 10 μg/kg) or sufentanil (0.5 to 1 μg/kg) is usually adequate to blunt the hemodynamic response to airway manipulation and surgical stimulation. Intermediate acting muscle relaxants (e.g., vecuronium, rocuronium, cisatracurium) are preferable over the longer-acting agents, and titrations by twitch monitors can be used. Inhalational or intravenous agents are used for maintenance.

Nitrous oxide can also be used but should be turned off promptly if conversion to CPB is anticipated.

## Anticoagulation

Heparin anticoagulation management varies between centers and depends on the surgical plan. If only one- to two-vessel CABG is planned, target activated clotting time (ACT) of 200 to 300 seconds is considered acceptable. For several graft anastomosis, using OPCAB with a mid sternotomy approach the ACT is targeted at 400 seconds. Heparin reversal strategies are also variable in that it is not routinely or completely reversed; in most cases protamine is given in small doses and ACT is checked aiming for the preoperative baseline.

## Hypotension Associated With Retraction and Compression of Heart

Preloading by IV fluid (crystalloid and/or colloid solutions) is used more liberally as compared to standard CABG because hemodynamic stability is more difficult to maintain in an intravascularly depleted patient. Fluid management should be guided by the cardiac filling pressures and echocardiographic findings. Hypotension can also be managed by the Trendelenburg position, adjustment of anesthesia, and use of vasopressors. Hypotension associated with arrhythmias should be corrected pharmacologically or electrically. Endocardial or epicardial pacing maybe required in the event of severe bradycardia or heart block. Inotropes (milrinone, dobutamine, dopamine, or epinephrine) may be needed in patients with a low cardiac output state. Cardiac positioning may result in compromised right heart filling; in this setting, opening the right pleural space by surgeon allows more efficient right heart filling during maximal cardiac displacement.

## Management of Intraoperative Ischemia

The general strategy is to optimize hemodynamics and maintain coronary perfusion pressure by administration of nitroglycerin and alpha-adrenergic agonists, and to reduce myocardial oxygen consumption beta blockers may be given. Use of intracoronary shunting during the distal anastomosis and initiation of intra-aortic balloon pump counter pulsation therapy are employed in select cases. The surgeon can also temporarily release the coronary occlusion or pericardial compression. Ischemic preconditioning (transient occlusion of the coronary artery and/or pharmacologic preconditioning with volatile anesthetics, etc.) before creating the distal anastomosis has been observed to reduce myocardial damage. Remember that some cases will

inevitably require conversion to the bypass pump.

## Extubation

The majority of patients are extubated in the intensive care unit (ICU) within 1 to 2 hours, although this varies on case-by-case and institutional basis. Some patients may be appropriate for extubation in the operating room.

### TAKE HOME POINTS

- Good anesthetic management is key to a successful OPCAB and is predicated on the basics: Optimize hemodynamics and maintain coronary perfusion pressure, communicate with surgeons, and keep an eye on the surgical field.
- There are known decreased risks in patients who receive OPCAB versus conventional coronary surgery: Stroke, renal failure, postoperative arrhythmias, bleeding and blood transfusion, systemic inflammation.
- Detection of myocardial ischemia with the EKG and TEE may be challenging related to repositioning of the heart.
- OPCAB may facilitate early extubation, early ICU discharge, and shorter hospital lengths of stay.
- OPCAB may be associated with increased mortality – further investigations are warranted.

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# What to Do and What Not to Do for Your Patients With Hypertrophic Obstructive Cardiomyopathy

John C. Klick, MD FCCP FASE FCCM and Kushal Shah, DO

A 20-year-old star men's college soccer player suddenly collapsed on the field during a game. The team travelled with a portable defibrillator, which was promptly and correctly used by the team's trainer, assisted by a parent who was an anesthesiologist and who jumped out of the stands to help. The athlete was noted to be in ventricular tachycardia before defibrillation, but fortunately regained consciousness with restoration of a sinus tachycardia. Upon questioning he admitted to experiencing some vague chest discomfort and shortness of breath over the past several months which he simply attributed to getting back into shape for the competitive season. As part of a later medical evaluation, he underwent a transthoracic echocardiogram which revealed significant left ventricular (LV) hypertrophy, left atrial enlargement, a small LV chamber size, significant septal hypertrophy, and systolic anterior motion (SAM) of the mitral valve causing mitral regurgitation.

He now presents to your preoperative clinic for anesthesia consult prior to surgical septal myomectomy. Review of his other past medical and surgical history is unremarkable. Family history is significant for a paternal uncle and grandfather with sudden death in their twenties. He is now taking atenolol (100 mg) each morning and has no allergies. Vital signs are as follows: Blood pressure 110/62 mm Hg, sinus rhythm at 64 beats/minute, and 100% oxygen saturation on room air. His physical examination reveals a noticeable double apical impulse and III/VI systolic ejection murmur at the left sternal border with radiation to the sternal notch, but not to the common carotid arteries. The murmur intensifies with upright posture, but decreases with squatting. Jugular venous pulse reveals a prominent a wave. A double carotid arterial pulse is noted. The electrocardiogram showed normal sinus rhythm with electrical criteria for ventricular hypertrophy and diffuse depression of the ST segments. He is very anxious to get back to the soccer field.

Hypertrophic obstructive cardiomyopathy (HCM) is the more recent term for the syndrome that was formerly known as HOCM or idiopathic hypertrophic subaortic stenosis (IHSS). It is increasingly recognized as a relatively common (estimated incidence of approximately 1/500) and under-diagnosed congenital cardiac abnormality. Although the disease is known to be a frequent cause of sudden cardiac death in young people, most affected patients are minimally symptomatic and have a normal lifespan.

HCM is an autosomal dominant disease with variable penetrance associated with mutations in the sarcomeric proteins. The main pathologic mechanisms include: LV hypertrophy, diastolic dysfunction, and arrhythmias. Asymmetric hypertrophy is the trademark of the disease with the interventricular septum being the most common area of involvement. Upper septal hypertrophy creates an area of narrowing and increases the velocity of the blood in the LV outflow tract, which in turn leads to a Venturi effect and SAM of the mitral valve. Two-thirds of these patients also have primary malformations of the mitral valve apparatus, including elongation of the mitral leaflets.

The end result of this physiologic pattern is a characteristic dynamic obstruction in mid-to-late systole. This systolic obstruction to flow can result in early closure of the aortic valve which produces a characteristic “spike and dome” arterial line tracing. The “spike” is created by early partial closure of the aortic valve due to SAM and the “dome” is created by reflected energy traveling along the aortic wall as it returns to the central aorta just before diastole. SAM resulting in significant mitral regurgitation will decrease forward cardiac flow. Increased inotropism, chronotropism, and hypovolemia can accentuate the dynamic obstruction in HCM patients and thus anesthesia care providers should deploy great vigilance in order to avoid these physiologic perturbations. The diastolic dysfunction associated with HCM translates into decreased ventricular compliance and leads to requirements for higher cardiac filling pressures and a dependence on the atrial contribution for adequate cardiac output—so keep your HCM patients full and do your best to avoid arrhythmias! Any type of arrhythmia can be associated with HCM, particularly atrial fibrillation (up to a 25% incidence) and malignant ventricular arrhythmias, thus establishing the significant risk of sudden cardiac death. HCM represents the most common cause of sudden cardiac death in young competitive athletes.

Medical management of HCM involves aggressive treatment with β-blockers or calcium channel blockers to reduce the inotropic state of the heart, to decrease heart rate in order to allow adequate filling time, and to promote maintenance of normal sinus rhythm. Therapeutic approaches available for symptomatic patients not responding to medical management are septal ablation with alcohol injection using percutaneous techniques (increasingly popular although not an option for all HCM patients) and the Morrow surgical septal myomectomy. The Morrow procedure involves an aortotomy

with resection of a small amount of muscle from the proximal ventricular septum, and involves the use of cardiopulmonary bypass (CPB) with cardiac arrest; complete heart block, creation of a ventricular septal defect (VSD), and aortic valve injury are associated complications of this procedure. Because these complications are relatively common, the importance of performing a complete post-CPB transesophageal echocardiographic (TEE) examination cannot be overemphasized. Operative mortality is quoted at less than 1%. HCM patients with a history of a malignant ventricular arrhythmia should have an implantable cardioverter-defibrillator (ICD) placed.

## TAKE HOME POINTS

- In providing anesthesia care for a HCM patient, **DO** be certain that the patient has undergone a recent echocardiographic assessment of their cardiac anatomy to gauge progression of their risk for dynamic obstruction. A complete history and physical examination may provide clues to pathology progression but in elective surgeries should not replace echocardiographic examination. Take care to inquire about shortness of breath, syncope, anginal symptoms, palpitations, history of arrhythmias.
- In providing anesthesia care for a HCM patient, **DO** be certain that if the patient has a strong family history of sudden death, or if they have a personal history of syncope, or a malignant arrhythmia that they have a functional ICD. **DO** be certain the patient is cared for perioperatively in a monitored bed with the means to immediately provide electrical therapy for a perioperative malignant arrhythmia. A negative electrophysiology study is not a sensitive predictor as to whether a HCM patient will suffer a malignant arrhythmia.
- While the preferred anesthetic approach for HCM patients requiring both cardiac and noncardiac surgery is the use of general anesthesia, **DO** consider that regional anesthesia can be safely used (for noncardiac surgical procedures only) as long as the patient is adequately anxiolysed and volume loaded prior to central neuraxial blockade. Vigilant maintenance of systemic vascular resistance with α-agonists, such as a phenylephrine infusion, is required with both general and regional anesthetic techniques. Arterial catheterization and monitoring promotes the success of these techniques.
- In providing anesthesia care for any procedure (cardiac surgery or noncardiac surgery) for a HCM patient, **DO** consider the use of central pressure monitoring in order to follow hemodynamic trends can be useful in these patients that may have elevated cardiac filling pressures related to chamber noncompliance. If available, use TEE continuously to assess the adequacy of ventricular filling and the degree of dynamic LV outflow tract obstruction.
- In providing anesthesia care for a HCM patient undergoing septal myomectomy, **DO**

consider that complete heart block and creation of a VSD are complications of this procedure. Performing a complete post-CPB TEE examination is essential and will rule out the presence of an iatrogenic VSD and aortic valve injury. In addition, it is important to document the resolution of the LV outflow tract gradient following septal myomectomy.

- In providing anesthesia care for a patient without a history of HCM but who has undergone a mitral valve repair (MVR), **DO** consider that SAM is a potential complication in this circumstance although the genetic sarcomeric abnormality does not exist in these patients. Medical treatment may be all that is needed and the return to CPB for MVR revision following MVR is not always necessary. Experienced anesthesia and surgical clinicians should be involved in such a decision and base their therapy on the post-CPB TEE examination results.
- In treating hypotension in HCM patients, **DON'T** employ agents such as dopamine, milrinone, norepinephrine, and ephedrine that have mixed inotropic, chronotropic, and peripheral vascular effects. Consider that the increase in heart rate and the inotropic state of the heart can acutely worsen hypotension related to dynamic LV outflow tract obstruction. Afterload augmentation, negative inotropic agents, maintenance of sinus rhythm, and maintenance of adequate intravascular volume are the treatments of choice in HCM patients.
- In planning the anesthesia induction of a HCM patient, **DON'T** rely heavily on agents such as propofol or thiopental that acutely sympathectomize the patient and abruptly reduce both venous and arterial tone. Narcotic and benzodiazepine combinations can have more subtle sympathetic depressive effects when used judiciously. Most contemporary volatile anesthetics, including isoflurane, sevoflurane, and desflurane, act as systemic vasodilators as well as myocardial depressants and thus should be used cautiously if at all.

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# Cardiac Transplant—Gotta Get This One Right

Edwin G. Avery IV, MD, Soon Park, MD, and Scott Streckenbach, MD

A 43-year-old female nurse with idiopathic cardiomyopathy and end-stage heart failure has been on Heartmate II™ left ventricular assist device (LVAD) support for 2 years awaiting availability of a suitable heart for transplant as a status 1B candidate (second-highest priority achieved by either being on an intravenous inotrope or a ventricular assist device at home). She has mild renal insufficiency, an implantable cardioverter defibrillator (ICD), and no active infectious issues due to the meticulous care she provided of her LVAD drive line site. Her right heart function is assessed as moderately depressed. Her last right heart catheterization demonstrated mild pulmonary hypertension (pulmonary arterial systolic pressures approximately 45 mm Hg). Donor organ compatibility has been confirmed and you get the call at 10 pm to head into the hospital and get her into the operating room as soon as possible.

How will you time your induction? What should you do with the ICD? What is your monitoring plan? Any issues with getting an arterial line in her? Are you worried about the function of the right heart following the transplant? Is bleeding a concern? How will you dose the immunosuppressants to minimize the risk of rejection?

Orthotopic heart transplant (OHT) is one of the wonders of modern medical therapy and is certainly the ultimate gift of life. So if you are in charge of the anesthesia for such a case, you are going to want to put your best foot forward and bring your "Anesthesia A Game" to the operating room! Gratefully, most centers that provide care for OHT patients have well-developed clinical protocols that take a lot of the guess work out of the process of getting these patients ready for their organ when it becomes available. Knowing the patient's current health status is very important as there are a number of issues that can disqualify them from receiving an organ (e.g., active infection or sepsis, renal failure, morbid obesity, loss of their insurance coverage).

## Important OHT Patient Preoperative Items

Make certain that the patient is not in significant organ failure and that there are no new infectious issues or other issues, such as morbid obesity (a body mass index of greater

than 35 kg/m$^2$ disqualifies a patient from OHT candidacy) that would obviate transplant. Always review the most recent right heart catheterization results to determine if the patient has appropriate pulmonary vascular resistance (PVR). It is important that the PVR be less than 6 Wood's units (mm Hg min/L) in OHT candidates. If the PVR is greater than 6 Wood's units but is reversible with dilator therapy (such as inhaled nitric oxide or intravenous vasodilator) to less than 6 Wood's units then the patient remains an acceptable OHT candidate. In most centers, the right heart catheterization is repeated approximately every 6 months or more frequently as the patient's clinical status dictates. If there is a question then these calculations should be made as soon as the patient's pulmonary artery catheter is inserted. It is unlikely that these patients will have a full 8 hours of NPO status, so plan induction strategy accordingly to include a rapid sequence induction if necessary.

Another extremely important and emotionally sensitive preoperative issue is to be certain that the patient understands that at any point in the process, up to the point when their own native heart is excised, the transplant may get aborted. While we make all efforts not to induce the patient into general anesthesia until we know that the donor organ is serviceable for the recipient, sometimes the proximity of the donor organ center or the need for extra preparatory surgical time (e.g., if the patient will be undergoing multiple redo-sternotomy) may preclude this. The bottom line is that the patient needs to know that even if they are induced into anesthesia, they may be awakened without a new heart. In addition, the recipient should understand that in rare cases the donor heart may require temporary mechanical support of right heart function (i.e., right ventricular assist device). Organ compatibility is established prior to the harvest and transport of heart to the recipient site.

## Immunosuppression for OHT

While we worry about infections in OHT patients, we certainly worry more about organ rejection, so these folks get "pickled in steroids." OHT centers will have different protocols, so be sure to know where to find that information at your hospital and know that the immunosuppression therapy starts BEFORE the organ is implanted with most protocols—remember steroids take some time to start working and both acute and chronic rejection are always a concern for OHT patients.

## Managing the ICD

Most end-stage heart failure patients will have an ICD. Although these devices are explanted during the OHT surgery after the organ is implanted, they should not be turned off until the patient is placed on an external defibrillator, especially if they have recently received any therapy from their device. If the patient is also dependent on the

device for pacing then simply turning off the device won't be sufficient. Deactivation of the ICD is necessary prior to surgical incision as the device will sense the electrocautery as fibrillation and will likely deliver shocks to the heart which could precipitate genuine ventricular fibrillation—such an arrhythmia could be difficult to treat in a sick heart so this situation is best avoided by reprogramming the device to deactivate the ICD feature (our electrophysiology colleagues are great at helping us with this). While placing a magnet on most ICDs is sufficient to deactivate the ICD therapy, it is not recommended because if the magnet slips off of the device during surgery the ICD feature can be reactivated which is a problem for the reasons already discussed.

In patients that are fully dependent on their ICDs for pacing it will be necessary to reprogram the device into an "asynchronous mode" because if the device is in a sensing mode it may inhibit the device's ability to pace the heart and create long bouts of asystole which may precipitate other life-threatening arrhythmias. A final ICD issue is to disable the rate response mode as the motion of the chest wall during the surgical preparation or a number of rapid breaths from the ventilator may trigger the device to deliver a faster paced heart rate which may not be well tolerated by the anesthetized native heart.

## Timing OHT Anesthesia Induction

Many factors go into the decision of how to time anesthesia induction in an OHT patient. These factors include: predicted time to prepare the recipient's chest for the donor organ, predicted time to establish invasive monitoring (such as arterial catheterization, central vein cannulation, pulmonary artery catheterization), and predicted travel time from donor organ site to recipient site. While there is no easy algorithm to follow on how to determine optimal timing for anesthesia induction of an OHT patient, one key feature of this process is frequent communication with our surgical colleagues, especially those responsible for organ harvest. The absolute last thing you want to do is create the situation where the donor organ is ready for implantation at the donor site but the recipient's chest is not prepared to accept the new organ! In this situation the donor heart's ischemic time (which begins when it is cross-clamped at the donor site) is needlessly prolonged. **It is well established that longer ischemic times are associated with a higher incidence of right heart failure; thus, this situation is best avoided at all costs.** In fact, it is a much better situation to be ready too early rather than too late in the OHT process. The maintenance of general anesthesia is similar to that of other heart failure patient anesthetics in that it may include use of benzodiazepines, narcotics, volatile anesthetics, and muscle relaxants as well as inotropes and vasoactive drugs that promote vital organ perfusion both before and after the donor organ is implanted.

## Monitoring for OHT

Standard American Society of Anesthesiology monitors are supplemented in OHT procedures by an arterial catheter, a central venous line, transesophageal echocardiography (TEE), and a pulmonary artery catheter. In some centers, left atrial lines may be used in lieu of or in addition to the pulmonary artery catheter. The use of cerebral oximetry is recommended to insure adequate regional cerebral oxygenation. While pulmonary artery catheters are used at most centers, some surgeons prefer that these be placed after the new organ has been implanted, so it is not in the surgical field during the anastomosis of the new organ.

One potential challenge in OHT patients is that their central veins may have been cannulated multiple times which may make establishing central venous access difficult. The presence of ICD or permanent pacemaker wires in the central veins can also make access difficult to impossible, so have a "Plan B" in your mind before you start on the central access for monitoring, such as femoral vein access for drugs/volume and a left atrial line to assess left heart filling pressures or float the pulmonary artery from the groin with TEE guidance.

Yet another potential challenge in OHT patients is establishing peripheral arterial access as many of these patients have undergone multiple cardiac operations. In those recipients with axial flow LVADs the arterial pulse will likely NOT BE PALPABLE—in this situation vascular ultrasound is your best new best friend forever (BFF)!

TEE monitoring is generally more helpful following implantation of the new organ, so do not spend too much time on the pre-bypass TEE examination. In the post-bypass period it allows one to establish that good vena cava flow is present and permits ongoing monitoring for signs of right and/or left heart failure.

## Right Ventricular Failure Risk in OHT

Right heart failure is likely the most feared acute intraoperative complication of OHT. While long donor organ ischemic times are associated with a higher incidence of this complication, there are other variables to consider. First, massive transfusion of red blood cells is associated with right heart failure, so coagulopathy should be treated early and aggressively with hemostatic allogeneic blood components to avoid this situation. In individuals with higher pulmonary vascular resistance, right heart failure may be more likely—consider that the donor heart is probably not accustomed to pumping against higher afterload. The bottom line is that the entire OHT team must be vigilant to detect right heart failure and be ready to treat it at a moment's notice.

Preferred medically-based right heart therapies include inodilators, inhaled pulmonary arterial dilators, and maintenance of higher systemic blood pressures through use of nonpulmonary vasoconstrictors (e.g., vasopressin). In addition, mechanical right

heart support therapies may include intra-aortic balloon counter pulsation or temporary right ventricular assist device implantation. All of these medical and mechanical therapies must be readily available at the time of organ implantation.

## Coagulopathy in OHT

Many OHT candidates are maintained on antiplatelet and antithrombotic medications to mitigate the inherent risk of thromboembolic complications associated with the low-flow state of many end-stage heart failure patients. Also consider that OHT patients with preoperative VADs require systemic anticoagulation. OHT candidates who have undergone previous sternotomy are at increased risk of hemorrhage. Most OHT patients also have some degree of hepatic congestion or renal insufficiency which both predispose to a higher incidence of post-bypass bleeding. Given these facts, one must always have allogeneic hemostatic blood components available prior to separation from bypass so that coagulopathy treatment can be addressed immediately.

## Waking Up the OHT Patient

It is never a good idea to extubate an OHT patient in the operating room immediately after surgery. Keep the patient anesthetized and transfer to the intensive care unit with functional monitoring to observe both the right and left heart function. Think of it like you want to give the heart a chance to get used to its new digs before the brain wakes up!

### TAKE HOME POINTS

- Important preoperative preparatory issues for OHT patients include establishing that no new disqualifying criteria have developed (such as infection, PVR >6 Woods unit, BMI >35 kg/m$^2$), reprogramming the ICD, and insuring that the patient has the clear understanding that although a potential donor has been identified, the process can be aborted for a number of reasons even after the transplant wheels have started turning.
- Immunosuppression protocols are of great importance for OHT patients to minimize organ rejection. This process is initiated prior to surgical incision so one must insure that these protocols are appropriately followed. Related to this issue is the need to use strict aseptic technique with the indwelling catheters.
- Timing of anesthesia induction is dependent upon multiple variables, such as predicted time of recipient preparation and predicted transport time of donor organ. Communication with the organ harvesting surgical team is of the highest priority to avoid unnecessarily prolonged donor organ ischemic time.

- Establishing both arterial blood pressure monitoring and central venous access can be very challenging in OHT candidates, so allow plenty of time to get these lines in.
- Right heart failure is the most feared acute complication of OHT, so you must vigilantly monitor the patient for any sign of this issue and be ready to treat it immediately.
- Coagulopathy is common in OHT patients given the nature of their disease process, so you must have hemostatic allogeneic blood components readily available to aggressively treat this problem if it is observed.

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# The Right Heart Should Never Play Second Fiddle to the Left Heart—What to Do When the Right Heart Just Really Ain't Right at All

Lindsay Wetzel, MD, Faisal D. Arain, MBBS MD, Daniel I. Asher, MD, and Edwin G. Avery, MD

A 72-year-old male with severe three-vessel coronary artery disease, hypertension, dyslipidemia, diabetes, and obesity presents for coronary artery bypass surgery. The patient's preoperative transthoracic echocardiogram (TTE) was notable only for low normal left ventricular systolic function (ejection fraction 45% to 50%) and impaired relaxation of the left ventricle. Following anesthesia induction that was conducted with midazolam, fentanyl, propofol, and rocuronium multiple doses of phenylephrine were required to maintain mean arterial pressures (MAP) above 70 mm Hg. Initial numbers from the pulmonary artery (PA) catheter revealed the following: PA systolic and diastolic 27 and 17 mm Hg, respectively, and a central venous pressure (CVP) of 17 mm Hg; the cardiac index was 1.7 L/min/$m^2$. Once the transesophageal echocardiography (TEE) probe was dropped it was noted that the right heart structures were dilated, appeared sluggish in movement, and mild tricuspid regurgitation (TR) was noted. How will you further quantify this patient's right ventricular function and what treatment approach, if any, may be needed?

Important: **The failing or failed right heart is NOT simply a passive conduit and shouldn't be treated as such! If you were told this in medical school, please be advised that this isn't true and never was true. Here are the basics of what you need to know about how to deal with the right heart.**

## Right Heart Anatomy

Right ventricular dysfunction is known to predict poor outcomes in patients undergoing coronary surgery and thus its presence should not be taken lightly. One of the key difficulties in the assessment of right heart function is related to the asymmetric shape of the right heart which is often described as a cornu, or horn. Individuals with right atrial

minor axis dimensions greater than 50 mm and tricuspid valve (TV) medial to lateral dimensions greater than 38 mm as measured from the mid-esophageal four-chamber view should raise serious concerns of chronic right heart dysfunction. By the general eyeball test, the right ventricle (RV) should be approximately two-thirds the size of the left ventricle (LV), and the apex of the heart should come from the apex of LV, not the RV. The RV shares the muscular interventricular septum with the LV and, even though they are neighbors, they sometimes do not get along. The interventricular septum can bow toward the LV in diastole if the RV is volume overloaded in a failing state which could give the LV less real estate, thus decreasing LV filling.

## Right Heart Dysfunction

The importance of good RV function is undervalued by many clinicians, but a failing RV can take anyone out to the woodshed for a lesson. The RV's main job is to propel deoxygenated blood through the normally low compliance pulmonary circulation for oxygenation and LV filling. A failing RV can impede adequate LV filling, impairing forward flow cardiac output. Quantifying RV function by visual estimation on TEE is complicated by its asymmetrical shape. However, tricuspid annular plane systolic excursion (TAPSE) is a relatively foolproof measurement of RV systolic and diastolic function. This measurement can be accomplished from a mid-esophageal 4-chamber view by simply measuring from just below the underside of the base of the anterior TV leaflet to the apex of the RV in both end systole and end diastole (Fig. 241.1). The difference between these two values is greater than 15 mm in normal RV systolic function and no mathematical genius is needed to perform this calculation.

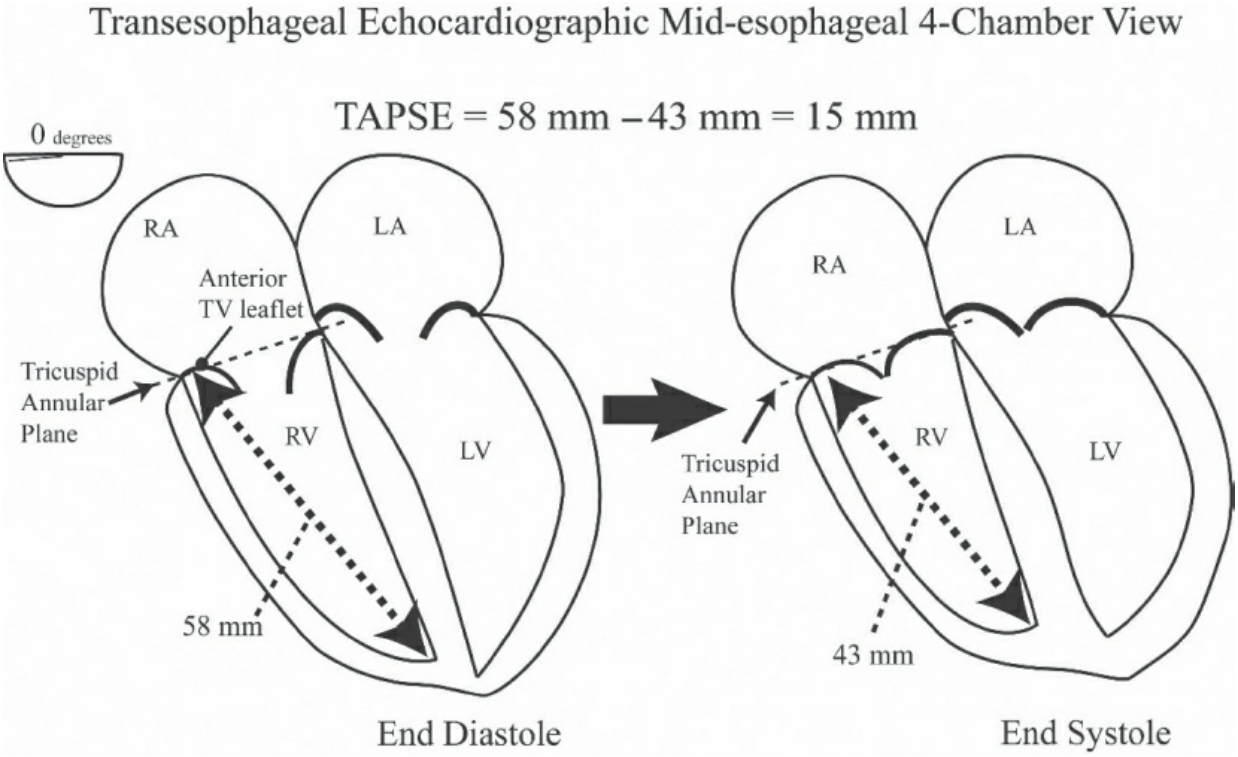


**Figure 241.1.** Illustration of an idealized transesophageal echocardiographic mid-esophageal four-chamber view at an omniplane of 0 degrees being used to calculate tricuspid annular plane excursion. LA, left atrium; LV, left ventricle; RA, right atrium; RV, right ventricle; TV, tricuspid valve; TAPSE, tricuspid annular plane excursion.

A PA catheter measures right-sided heart pressures and right-sided cardiac output by thermodilution and can, in conjunction with TEE, be helpful in making the diagnosis of RV dysfunction. For example, in our presented case above, the cardiac index is unacceptably and unexpectedly low. The PA mean pressure (diastolic is high) appears normal but the CVP and PA diastolic is on the high side—this is a big clue that we were dealing with clinical right heart failure. The low PA pressures and low PA pulse pressure are also clues that RV systolic function is poor; TEE visualization and a TAPSE of less than 10 mm will confirm the diagnosis. Direct observation of poor RV wall thickening during systole by TEE can also be helpful for qualitative measurement of RV function. Note that the mild TR observed in this patient is a bad sign in that the RV systolic function is so poor that even with a severely dilated tricuspid annulus the RV cannot generate much TR. We get it that this stuff is a little complicated, but, hey, if it were easy the surgeons wouldn't need us to figure this all out.

A standard intraoperative TEE probe cannot practically be used to continually monitor RV function in the ICU, but there are a few other options. In the intubated patient, one can use a miniature TEE probe (ClariTEE©) which provides an adequate diagnostic image in most patients to perform serial right heart examinations without the need for repeatedly removing and reinserting the TEE probe. This device can remain in

the patient for up to 72 hours which coincidentally is probably how many hours we all work in any single given week. TTE can also be used, but is limited in the postoperative period due to air, blood clots, or acoustic shadows in the chest or external dressings that can impede adequate visualization. Probably the most practical, though invasive, approach for continuous right heart monitoring is the PA catheter.

Focusing on the ratio of the PA diastolic, mean, or systolic pressure to the CVP is a clinically useful way to serially assess right heart failure. When the PA:CVP ratio goes down (i.e., lower PA pressures and higher CVP) it is a sign that RV function is worsening in that it can no longer effectively pump blood into the PA. Both volume and pressure are backing up from the right heart into the venous circulation. An opposite change in the ratio of PA:CVP (i.e., higher PA pressures and lower CVP) is a favorable sign of good RV function. So a little more basic math goes a long way here in terms of keeping a watchful eye on RV function with our PA catheter.

## Treating Right Heart Dysfunction

So once we have established the diagnosis of RV failure using the quantitative and qualitative data from the PA line and the TEE, we need a good treatment plan.

**The Don'ts:** In most situations, administration of more intravascular volume is not a good idea because it will further stretch the already dilated RV, pushing it off its Starling curve, and likely hastening complete RV failure. Giving volume to a fluid overloaded RV may remind us of the beer bong college days when it also turned out to be a bad idea to pound all that cold, foamy volume into the relatively small stomach. That activity was inevitably followed by uncomfortable physiologic reflexes as the through-put capacity of the system was overwhelmed. Intravenous administration of pure alpha-1 vasoconstrictors, like phenylephrine, is another bad idea as it will increase pulmonary arterial vascular resistance (i.e., right heart afterload) and reduce RV output. That being said, it's true that increasing MAPs (i.e., usually to just above 80 mm Hg) can improve RV perfusion pressure and performance, just as long as the higher MAP doesn't come along with a ton of increased pulmonary vascular resistance. We also recommend going easy on the positive end expiratory pressure (PEEP) as values above 5 mm Hg may functionally limit right heart filling and may further reduce overall cardiac output.

**The Do's:** The best drug cocktail for the failing right heart is what the late Rodney Dangerfield might call "The Triple Lindy" of supportive right heart moves and includes three drugs: intravenous milrinone for contractility, a selective pulmonary vasodilator (e.g., inhaled nitric oxide or inhaled epoprostenol), and vasopressin as needed to maintain a higher mean arterial pressure (e.g., 80 mm Hg). Vasopressin is made for this job because there are no vasopressin receptors in the pulmonary arterial vasculature

which helps to avoid unwanted increases in pulmonary vascular resistance. Other approaches in less severe RV failure may be to use epinephrine or dobutamine to increase RV contractility. One can also use a low-dose nitroglycerin infusion to help decrease PVR and increase RV perfusion. However, this is obviously limited by the need for adequate MAPs.

**Out of your league with drugs:** Don't call a personal injury lawyer; instead just note that in the most severe cases of RV failure, it may be necessary to leave the chest wall open to allow for optimal RV filling. This situation may be appropriate in our clinical case as RV failure may be expected to get better within 12 to 24 hours following coronary revascularization. Under the most dire circumstances, mechanical circulatory support devices must be considered and can include an intra-aortic balloon pump (IABP), venoarterial extracorporeal membrane oxygenation (VA-ECMO), dedicated right ventricular assist devices (RVAD) such as the Centrimag©, or a combination of them. The mechanical support device used will depend on the experience and preference of the cardiac surgeon and will differ from center to center.

A caveat to keep in mind with RV failure is that use of an IABP will potentially worsen RV failure. The RV relies upon developed LV systolic pressure which creates a firm interventricular muscular septum to beat against in order to help propel blood into the pulmonary circulation. Because the IABP deflates during systole it creates a sort of vacuum in the aorta and hence reduces developed LV systolic pressure. Under these conditions the RV doesn't have a firm muscular septum to beat against and RV output may fall. It's a little bit like that dirty trick you may have played on your buddy when you're on the see-saw (or your grandfather may have played on his buddies—this childhood prank seems eternal). That is, the physiology of the right heart, like a see-saw, relies on the law of opposing forces. Your buddy relies on your weight to keep them up in the air while you are down on the ground and if you abruptly jump off the see saw when they are up in air they lose the support needed to keep them up in the air and come crashing down on their tail bone, ouch! And so it is with the right and left hearts and the interposing septum.

## Tricuspid Valve Regurgitation

TR is most commonly functional in nature meaning that it is related to dilation of the RV and likely also the TV annulus. The mechanism of functional TR is when the RV chamber dilates it results in displacement of the RV papillary muscles which make up part of the TV subvalvular apparatus; the displaced papillary muscles pull the TV leaflets apart allowing regurgitation. TR can also be caused by infection-endocarditis, iatrogenic reasons, or external blunt or penetrating trauma which damages the TV apparatus. Severe TR is marked by a vena contracta width of greater than 0.7 mm in the

mid-esophageal four-chamber view. Secondary changes associated with severe TR are as follows: TV annular dilation, RA dilation, vena cava dilation, holosystolic flow reversal in the hepatic veins, and hepatic congestion-induced coagulopathy (i.e., there may be a prolonged partial thromboplastin time or International Normalized Ratio related to poor hepatic perfusion brought on by the high venous pressures).

TR is best managed during anesthesia by not allowing the heart rate to decrease as this will result in an increase in the regurgitant fraction that will ultimately decrease RV output. Both chronotropic intravenous drugs or electrical cardiac pacing can prevent bradycardia-induced exacerbation of TR. Drugs or physiologic changes that can increase pulmonary vascular resistance can all be expected to worsen the degree of TR (e.g., alpha-1 vasoconstrictors or hypoventilation, hypoxemia, hypothermia, acidosis, etc.). We are starting to sound like our internist colleagues that tell us to avoid all of these things that are obviously bad, sorry about that, but we just can't let it go unsaid. Since it is always easier to stay out of trouble than it is get out of trouble in cardiac surgical patients, we recommend running an intravenous dobutamine infusion prior to anesthesia induction in patients with severe TR to avoid bradycardia.

The age-old decision to repair or replace the TV in the setting of moderate or worse TR should consider the degree of involvement of the subvalvular apparatus (i.e., TV ring annuloplasty repair will not be effective in rheumatic TV disease). Functional TR responds well to a ring annuloplasty repair and care should be taken to obtain trans-TV gradients following repair to rule out iatrogenic TV stenosis (i.e., mean gradients less 6 mm Hg with a normal cardiac index are desirable). TV endocarditis normally requires replacement of the valve. **CAUTION:** Note that under general anesthesia which can be accompanied by sympathectomy and unloading of the right heart that the degree of TR observed may significantly underestimate the amount of TR present when the patient is awake or in severe pain for whatever reason. In such cases acutely volume loading the right heart by placing them in steep Trendelenburg position may better reveal the patient's actual degree of TR. Intravenous administration of an alpha-1 vasoconstrictor may also better reveal the actual degree to TR. It is also helpful to look for secondary signs of TR, like RA dilation, in the absence of an impressive TR jet to help make the decision of whether a TV repair is indicated.

## Tricuspid Valve Stenosis

TV stenosis is rare in most US-based clinical practices. It may be related to rheumatic disease, endocarditis, or carcinoid disease. Stenotic TVs are almost always replaced. Anesthetic goals are to maintain right heart preload, normal sinus rhythm, and mid-ranged heart rate of approximately 70 to 90.

## TAKE HOME POINTS

- Right ventricular dysfunction remains a significant cause of morbidity and mortality in patients undergoing cardiac surgery. Early identification of RV dysfunction may improve risk stratification and lead to early management of RV failure, so whatever you do don't blow off assessment of the RV!
- Although RV assessment remains challenging secondary to its complex anatomy, the tricuspid annular plane systolic excursion (TAPSE) measurement provides a reasonable index of global RV systolic and diastolic function and you don't need a PhD in physics or mathematics to master the technique.
- RV dilation can cause a leftward shift of the ventricular septum, modifying LV geometry. As a consequence, both LV distensibility and contractility may decrease resulting in reduced cardiac output. In the same manner, in patients requiring LVAD or IABP support, unloading of the LV alters RV size and shape and may lead to further RV failure which, like your dad may have said to you when you were growing up, "is exactly the situation we are trying to avoid."
- In patients with a failing right heart, the top shelf drug cocktail is what we like to call "The Triple Lindy" of supportive right heart moves and includes: intravenous milrinone (i.e., increases RV inotropism and decreases pulmonary pressures), inhaled selective pulmonary vasodilators (e.g., inhaled nitric oxide or inhaled epoprostenol), and vasopressin (i.e., useful to increase mean arterial pressures greater than 80 mm Hg to promote better right heart coronary perfusion without increasing right heart afterload).
- Functional tricuspid regurgitation (FTR) is usually a prominent feature of RV dysfunction and may be the result of RV dilation and pulmonary hypertension. FTR generally responds well to TV ring annuloplasty so tuck this fact under your surgical cap.
- Because it's easier to stay out of trouble than to get out of trouble in cardiac surgery, we recommend that a dobutamine infusion is run prior to anesthesia induction in patients with known moderate to severe, or worse TR.

## Suggested Readings

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Rudski LG, Lai WW, Afilalo J, et al. Guidelines for the echocardiographic assessment of the right heart in adults: a report from the American Society of Echocardiography endorsed by the European Association of Echocardiography, a registered branch of the European Society of Cardiology, and the Canadian Society of Echocardiography. J Am Soc Echocardiogr. 2010;23(7):685–713.

## SECTION XII

# OBSTETRIC ANESTHESIA

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# Introduction

Christopher E. Swide, MD

Obstetric Anesthesia. It brings up memories of frequent pages, 24/7 coverage, urgent cesarean sections. But it is primarily a practice that involves two, and sometimes more, patients and other extremely involved participants. A mother and a child. A father-to-be. A concerned nurse. A worried obstetrician. It is a practice that one must manage outside of the "OR schedule." To be available at all times to provide pain relief or safe patient- and family-centered care. To be part of an important day in your patients' lives. To appear in the baby book. To see the smile on a mom's face when you relieve her pain or manage a complicated delivery. It is an honor and privilege to be part of such important moments. The chapters within this section will provide common sense approaches to challenges and patient management in the labor suite and delivery room. I hope you use these chapters to further enhance your practice to help women, babies, and their families.

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# Be Prepared for the Presence of a Doula in Both the Labor and Delivery Rooms

Christopher E. Swide, MD

Doulas are becoming increasingly popular in the United States and are active on many labor suites across the country. DONA International is the oldest and largest of the doula organizations in the United States. It has more than 5,800 members, including 2,300 certified birth doulas in all 50 states. Many hospitals and health systems hire doulas directly, but it is also common for doulas to contract separately with the patient. The term **doula** is derived from Greek and refers to the most important female servant in the ancient Greek household. Today's doulas are caregivers whose primary role is the emotional support of the mother during labor and delivery. Anesthesiologists and nurse anesthetists working on labor units will encounter doulas but are often confused about their role in the birth experience. It is important for them to have a general understanding of this caregiver's role to facilitate optimal care for obstetric patients.

**Doulas are not licensed providers**; therefore, there are no state requirements for doula education. However, DONA International offers a certification program that consists of completing a reading list; completing a workshop of a minimum of 16 hours; and documentation of previous experience in childbirth care by training in childbirth education or midwifery, work experience as a labor nurse, or observation of a childbirth preparation series. After completion of this program, the new doula must provide service to at least three clients and document the births with a 500- to 700-word firsthand account of each experience. In addition, the new doula must provide evaluations from three clients, three primary care providers, and three nurses or midwives.

**Doulas do not provide clinical care to the mother**. They do not make clinical decisions or offer opinions that might influence their clients' decisions. **A doula that is also a midwife, nurse, or another care provider, cannot function in those roles while serving as a client's doula**. Their primary role is emotional support of the mother, and facilitating positive communication between the mother, her nurses, midwives, and physicians. They maintain continuous presence during labor and help the mother's

partner be part of the experience.

Although many doula clients do not want regional anesthesia for labor, a significant number of patients still expect or decide to receive a labor epidural for pain relief. It is important for the anesthesia provider taking care of these patients to interact with the patient and the doula. Patients with doulas must consent to having the doula present for confidential medical discussions. The doula will expect to be in continuous attendance with the mother, and this should be respected unless there are medical or hospital policy rules that do not allow it. Doulas can be helpful to the anesthesiologists and nurse anesthetists, often comforting the mother during the placement of the regional block and maintaining communication patterns between the patient, the nurses, physicians, other caregivers, and the partner during labor.

If a patient needs cesarean section, the doula should be included in the discussion and planning made to accommodate the doula in the operating room, if feasible. In the case of urgent cesarean section requiring a general anesthetic that precludes doula presence, the situation should be discussed with patient and doula, and all efforts made to preserve the team approach for delivery of the baby and to maintain respectful interactions.

In summary, doulas can provide obstetric patients with excellent emotional support and increase the mother's satisfaction with her birth experience. It is important for anesthesia providers to understand the doula's role and incorporate the doula into the overall care plan, so that patients who choose doulas can have an optimal birth experience.

## TAKE HOME POINTS

- Take the time to understand the doula's role in childbirth.
- Respect the mother's choice in choosing a doula to participate.
- Introduce yourself to both the patient and the doula.
- Maintain respectful and professional interactions throughout the care of the patient.
- **Learn the policy of your labor unit concerning doulas. If you are an OB anesthesia trainee, make sure to ask your teaching faculty about their experience and advice pertaining to doulas.**
- Make patient care decisions and recommendations as you would with any patient in labor. Your standard of care does not change with patients using doulas. The parturient is the doula's client, but your patient. And remember, be respectful always.

## Suggested Readings

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# Guests on the Labor Deck and in the Delivery Room—How to Manage It and Keep Your Professional Demeanor

Christopher E. Swide, MD

The labor and delivery suite is one of the few places in the hospital where family and friends are almost universally present during procedures that are fraught with risk (the other being the induction of pediatric patients with the parent present). **The obstetric anesthesiologist must have not only the clinical skills to deal with the medical management of parturients but also the social and communication skills to manage guests**. In the obstetrics environment, the patient's family and friends are often in the immediate vicinity. They can be distracting to care providers and may become stressed themselves by witnessing emergency care procedures. Unlike other chapters in this book that address anesthetic emergencies, this chapter focuses on methods for handling the potential repercussions of managing anesthetic emergencies **in the presence of guests. And, as we discuss below, to be successful at this aspect of clinical practice, the anesthesia provider must view the obstetric nursing staff as true partners and valued allies for a good interaction with the patient and her guests.**

Every anesthesia provider must develop a practice model concerning guests. It is important that this model meet the needs of all "clients" (mothers-to-be, family and guests, the baby, the obstetrician, and the labor and delivery nurses) as well as his or her own needs. Fortunately, there is help available in handling these situations:

) **Follow institution policies.** Hospital policies govern who can be in the delivery room or operating room (OR), and include processes of limiting access for medical cause as determined by the obstetric and anesthesia providers. Do not go outside your institution's policies for any reason.

) **Communicate with the labor nurses**. The nurses taking care of the patient often have a good understanding of the relationship dynamics of the patient's family and friends. Thus, the nurses can provide excellent advice on how to best broach the subject of presence during procedures. It is also important that the nurses, physicians, and other

providers on the unit make a unified decision.

- **Communicate with the obstetric provider.** The obstetric provider can be invaluable in helping the patient and her guests understand that the people she selected to be present at her delivery may be asked to leave the room if the care management plan necessitates it.

- **Communicate with the patient**. Discuss the potential of asking guests to leave the room if necessary during a procedure as part of the basic patient interview. It is the author's practice to **always** discuss this and to make sure the guests know that it is in the best interest of the patient.

- **Always remain calm and professional.** Even in the midst of a real emergency or with an angry patient or guest, this is an important rule. If you must ask a guest to leave, try to frame it in terms of being able to best help the mom and the baby, rather than making it a contest of wills or control struggle.

- **Use the institution's patient advocate**. Patient advocates are trained professionals who are invaluable in dealing with stressed and angry patients, family members, and health care providers. These advocates can be used if the previous strategies are ineffective. This step almost always works to avoid utilization of the last step, which is activation of the security team.

If all else fails, and if the anesthesia provider believes that guest presence puts the patient (or the provider) at risk, the last step is calling in the institution's security team to escort the guests from the scene. Proper preparation and utilization of the other techniques almost always solves the problem before the need for security.

## Helpful Hints for Managing Guests

These tips are considered reasonable by most obstetric anesthesia providers. **Before the start of care:**

- You MUST check privately with the mother-to-be regarding her desire for guests in general as well as individual guests in particular. Remember that parturients are emancipated minors. So no matter what the patient's age is and regardless of her cultural background or family situation or any other factor, she has the absolute legal right to a private conference with her care providers and to make an autonomous medical decision for herself about her care, including her guests. Private conversations with the mom-to-be should be witnessed by another medical provider.

Exceptions to this practice rule will be extremely rare, for instance in the unfortunate situation of a parturient who has a significant pre-existing cognitive disability.

- Try to ascertain how much medical knowledge the guest has. Sometimes guests with a degree of medical knowledge may have control issues.
- In discussion with guests, always mention that the pace can quicken even in routine deliveries and find out how people will feel about being asked to step out.
- There are warning signs that may predict for a difficult or disruptive guest: confrontational and angry interactions with staff, poor interactions with the patient, and poor communication skills. Do not allow these people in the room in the first place.
- Exercise caution in allowing "guests to support guests." This situation sometimes arises with when the couple having the baby are themselves very young—for example, an older female family member might request to be in the room to support a teenaged father or the other very young mother. This is felt by obstetric anesthesia providers to be a somewhat gray area. Allow it only if you feel the extra person(s) will help the care team better care for the patient.

## For the Labor and Delivery Rooms

- There is no real limit on the number of support people except for space. The nurses will often help provide crowd control in the labor rooms, so things do not get out of hand. Usually everyone except one person is asked to leave during procedures; however, anesthesia providers may reserve the right to have all guests leave the room if the epidural is anticipated to be difficult.
- **Guests must sit! There are no exceptions to this.** Guests must also remain in front of the patient, so that means that a guest should never act as the "holder" for an epidural. The sitting parturient may place her feet on the knees of the sitting support guest during epidural placement if that is comfortable for the patient and her guest.

## For the OR

- Usually only one person is allowed in the OR for C sections, sometimes more if the anesthesia provider has met them and agreed beforehand to have them as guests.
- Guests may come and go from the OR only with an escort. Have a prearranged method to get a guest who gets woozy out of the delivery room. Remember that it is possible to faint from a chair—one of the editor's brother fainted at the operative delivery of his t**hird** child, having sailed through the birth of his first two children without so much as a blink.
- After the baby is delivered, guests may approach the baby warmer only if the okay is given by the delivery team (including the pediatric team, if they are there).
- Usually no guests are allowed in the OR until the block is in and working. However, a

support person can occasionally be allowed into the room for the block, if the anesthesia providers believe that it may **help them** do their job more efficiently.

## In General

- Guests must be a minimum of 18 years of age to be in the room for C sections (unless the guest is the father of the baby). There is no age minimum for labor and delivery rooms.
- Expect as you gain experience that your practices will both loosen and tighten. This author has loosened up on the number of people in the OR, provided they do not interfere with the tasks of the anesthesia team, but tightened up about moving guests out if needed and very much tightened up about only one support person for labor epidurals and no videotaping of procedures.
- The doula is a member of the patient's care team and does not count as a guest.
- Cell phones are now everywhere in the clinical environment. At our institution, some practitioners encourage the spouse/partner to bring a cellphone into the OR to take pictures of the baby immediately after delivery. However, planned cellphone use should be reviewed before an operative delivery, as the obstetrician may have also had a discussion with the patient and her guest.

**A final note from F. Jacob Seagull, PhD:** Successful obstetric anesthesia providers instinctively use a human factor approach for the management of guests in the obstetric suite. In other words, you will do well to create an environment in which expectations are clear, and plans are discussed in advance. Doing this means that when the time comes, you will be activating an existing plan, not explaining a new plan, managing expectations, explaining your actions or trying to calm worried guests. By discussing the actions beforehand, you can address any questions while everyone is calm. You can effectively "offload" the bulk of the tasks involved in getting people out of the labor and delivery rooms to your low-workload times. This offloading is what experienced anesthesia providers do in planning any difficult case, by preparing in advance for contingencies.

Tell the guests that they may be asked to leave for a number of reasons pertaining to the ongoing management of the patient (noise level too high, arrival of extra care team providers, need to treat the patient for non–life-threatening events such as vomiting, a new peripheral IV, etc.), but that are not indicative of a true crisis. Guests will have a cognitive framework of the range of possible circumstances in which they might be asked to leave, and therefore may not assume the worst. They will be happy to "implement a plan" when the time comes; you will be happy that you don't have to explain the situation. The goal is to try to arrange a win–win situation.

## TAKE HOME POINTS

- Utilize as many sources as possible in developing your practice in managing guests on the Labor and Delivery deck and the OB operating room. Start with your hospital's policies, always. Talk to and learn from senior colleagues and more experienced providers on the physician and nursing sides on how they have handled these situations—what has worked and what hasn't. Acknowledge and accept that your practice will change as you become more experienced.
- The final decision is yours after consultation with the patient. The wishes of the other medical providers and the family come second.
- Don't let a "problem" guest in the room to start with.
- **Guests must sit** and be escorted into and out of the room. Guests should never be pressed into the medical care of the patient.
- The "fainting stories" are not just folklore. All kinds of guests have been known to faint while supporting a parturient, even during epidural placement. This includes experienced medical professionals, combat veterans, and public safety personnel who have been present at many bloody trauma scenes, such as state police officers and firefighters. Unfortunately, lawsuits have resulted.
- Never lose your cool.

## Suggested Readings

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# Alternatives to Epidural Analgesia for Labor Pain—What to Consider, What You Might Be Asked

Karen Hand, MB BS FRCA

Epidural analgesia is widely used in the United States and other developed countries, with approximately 60% of women overall receiving an epidural and even higher numbers for first babies. Neuraxial analgesia is generally very safe but there are circumstances in which its risks are increased or when it is contraindicated. Although neuraxial analgesia is generally popular among laboring women, many wish to use alternative methods of analgesia. Providing safe and effective analgesic techniques for women not desiring, or unable to have an epidural, may improve maternal satisfaction with labor analgesia. Having effective alternative techniques may also reduce the temptation to take risks with epidural analgesia. If your bottom line for platelet count is 75, what do you do with a platelet count of 70? If you know your patient has Harrington rods down to L5 are you going to try a neuraxial technique? It's good to have an alternative.

There is a range of very low-risk approaches to labor analgesia including psychological techniques such as emotional support, meditation, and breathing techniques. The water bath, massage, and aromatherapy may also be used. Midwives use interventions such as sacral saline injections and TENS stimulation. However, this chapter will focus on three techniques which may be considered intermediate in terms of potential efficacy, labor intensity, and medical involvement—remifentanil patient-controlled analgesia (PCA), nitrous oxide analgesia, and acupuncture.

## Remifentanil PCA

Remifentanil is an ultra–short-acting synthetic opioid. It is generally given by infusion. However, for labor analgesia it may be administered via PCA as a small bolus dose, either with or without a background infusion. It has become the opioid of choice in many centers for use with a PCA when an epidural is contraindicated.

Opioids have been the mainstay of labor analgesia in the past having the advantages

of being cheap and readily available. Their disadvantages include their limited efficacy for labor pain and side effects for both the mother and baby, particularly respiratory depression. To avoid respiratory depression in the neonate, opioids must be limited close to delivery. Meperidine has traditionally been the opioid of choice for labor analgesia, with less risk of respiratory depression, although as an alkaline drug there is a risk of ion trapping and accumulation in a distressed, acidotic fetus.

Labor pain in the first stage is experienced primarily during contractions. Remifentanil PCA may effectively treat the pain of contractions without the risks of longer-acting opioids, particularly accumulation in the fetus. It has the advantage of offering the mother an element of control over her pain.

Remifentanil PCA is administered as a bolus dose of, for example, 0.25 to 0.5 mcg/kg with a lockout period of 2 minutes. A background infusion can be added, with rates of, for example, 0.025 to 0.05 mcg/kg/min. An infusion may increase the efficacy of remifentanil but may also increase the risks.

The risks of remifentanil infusion include maternal bradycardia and respiratory depression. Maternal deaths have been reported, as has neonatal respiratory depression.

Remifentanil PCA requires careful monitoring and staff training. It is generally considered as an alternative when neuraxial analgesia is contraindicated, rather than as an attractive option in itself. It has been described negatively as "a poor man's epidural."

## Nitrous Oxide

Nitrous oxide is an anesthetic gas which is widely used worldwide in subanesthetic concentrations for labor analgesia. Its use is reemerging as an option for labor analgesia in the United States. It is popular among midwives and their patients. It is perceived as a safe and relatively simple option. For women desiring an "unmedicated birth" it may be viewed differently from other drugs.

Nitrous oxide for labor analgesia is administered by face mask or mouthpiece as a 50% mix with oxygen, utilizing a demand valve opened by inspiratory effort. The mother is instructed to take deep breaths at the onset of the contraction as she feels it begin to build, because the analgesia is slightly delayed. It is important that she stop inhaling nitrous oxide between contractions and that she holds the mask herself.

Advantages of nitrous oxide include that it is relatively safe in the 50:50 mix, with little risk of sedation. It is relatively cheap and easy to administer. It has a quick onset and offset of action, so can effectively treat the pain of contractions without accumulating in the mother or fetus. It offers the woman a sense of control over her own analgesia.

There are some contraindications to nitrous oxide analgesia. Nitrous oxide is more

soluble than nitrogen so accumulates and expands air-filled spaces, so must be avoided in a woman with, for example, a pneumothorax, or some types of recent eye or ear surgery. A woman who cannot hold the mask herself should not use nitrous oxide. Nitrous oxide interferes with B12 metabolism so should be avoided in a woman with confirmed B12 deficiency.

Nitrous oxide has some disadvantages. It's efficacy for labor analgesia is limited compared to neuraxial analgesia. It is probably best compared to opioids in terms of analgesia; however, this may be adequate for many women. Nitrous oxide may exacerbate hypoventilation and desaturation between contractions. Nitrous oxide may be less helpful than epidural analgesia for the woman desiring an unmedicated birth who becomes exhausted. For women at high risk of cesarean section or at high risk of complications, if general anesthesia is required, an epidural has the advantage that it can be used for anesthesia.

Nitrous oxide is a potent greenhouse gas, with an effect on the atmosphere 100 times that of carbon dioxide. There are also concerns about its potential adverse effects on hospital staff. There have been reports of increased rates of abortion in exposed hospital staff, although studies have not confirmed this. Nitrous oxide must be effectively scavenged. It may be expensive to install built-in scavenging to a labor and delivery suite. There are nitrous oxide and oxygen delivery devices available which utilize standard wall suction for scavenging.

Despite its widespread use worldwide, there are few randomized controlled trials of nitrous oxide labor analgesia and no studies of its long-term effects on the fetus. Apoptosis of developing neurons as a result of exposure to anesthetic agents is a current concern under investigation. A detrimental effect of fetal exposure to nitrous oxide during labor cannot currently be excluded.

## Acupuncture

Acupuncture is a complementary medical modality, which is widely used in the United States and Europe, as well as in China, its historical home. Acupuncture has a growing body of research behind it. It is very popular, with 6% of the US population having used it for various ailments. Theoretically, acupuncture is an ideal adjunct for analgesia in labor because it is relatively free of side effects and may have beneficial effects on the progress of labor, although in the framework of Western medicine, the placement of needles at points seemingly unconnected to the neuroanatomical pain pathways may seem bizarre.

Acupuncture involves placing fine needles at specific anatomical points, with a view to influencing the circulation of "chi" or "qi." "Qi" is a term used in traditional Chinese medicine which does not have an equivalent in Western medicine, but is something like

life force, or energy, which circulates in specific channels or meridians. Diagnosis and selection of acupuncture points can be taken to a high art. However, at a basic level, a limited number of points known to be beneficial in labor can be used effectively.

The research data on acupuncture for labor analgesia are mixed. A Cochrane review of labor analgesia placed acupuncture and acupressure in the "maybe" group in terms of evidence of efficacy. However, there is high-quality evidence supporting the efficacy of acupuncture for some other indications of interest to anesthesiologists, particularly prevention of postoperative nausea and vomiting, which suggests that further research for acupuncture in labor is warranted.

Acupuncture research is hampered by our lack of understanding of how acupuncture works. Studies often include a "sham" arm, although there is a lack of agreement on how to use "sham" acupuncture in a way which will clearly delineate placebo effects. Some will argue that there is already sufficient evidence that acupuncture is more than placebo, and that study of acupuncture in comparison with other accepted treatments is more helpful. Studies vary in terms of the acupuncture points chosen, whether or not electrical stimulation is used, the duration of treatment, and the setting and personnel providing the treatment; so it is hard to evaluate the sum of evidence. For labor analgesia, pain scores may not tell the full story. Maternal satisfaction and coping scores may be more helpful. What we do know is that acupuncture affects release of endogenous opioid, as well as oxytocin.

There is evidence that acupuncture delays the time to request for epidural analgesia, and that women using acupuncture would choose to do so again. Acupuncture was found to be inferior to sacral saline injections, although this technique may actually be acting on sacral acupuncture points.

There are various ways to provide acupuncture for labor analgesia in the hospital setting. In the United States, most acupuncture in the community is performed by specialists in Traditional Chinese Medicine, known as licensed acupuncturists. Many women utilize the services of licensed acupuncturists during pregnancy, whether for nausea, carpal tunnel syndrome, breech presentation, or initiation of labor. In some settings it may be possible to enable women to have their licensed acupuncturist accompany them into the delivery suite, in the same way that they are accompanied by their chosen doula. Other hospitals may employ licensed acupuncturists to provide a similar service. In the United States, in most states, physicians are able to train to provide acupuncture, with a minimum of 200 hours of additional CME training. However, most of us who have done this training don't find it practical to be on-call for acupuncture for labor analgesia. This will not usually be a cost-effective way of utilizing the skills of an anesthesiologist, and the financial remuneration is far less than for anesthesia services. In our hospital we have an innovative program which allows

anesthesiologists to train and be accredited in very limited, single-point acupuncture for the prevention of postoperative nausea and vomiting. We have ongoing studies of simple one- or two-point acupuncture for a variety of perioperative indications. A training and accreditation program allowing staff who are already present on the labor and delivery suite to provide a limited acupuncture service may be a practical option, whether that is the obstetric anesthesiologist, or if regulations allow, midwives or nursing staff.

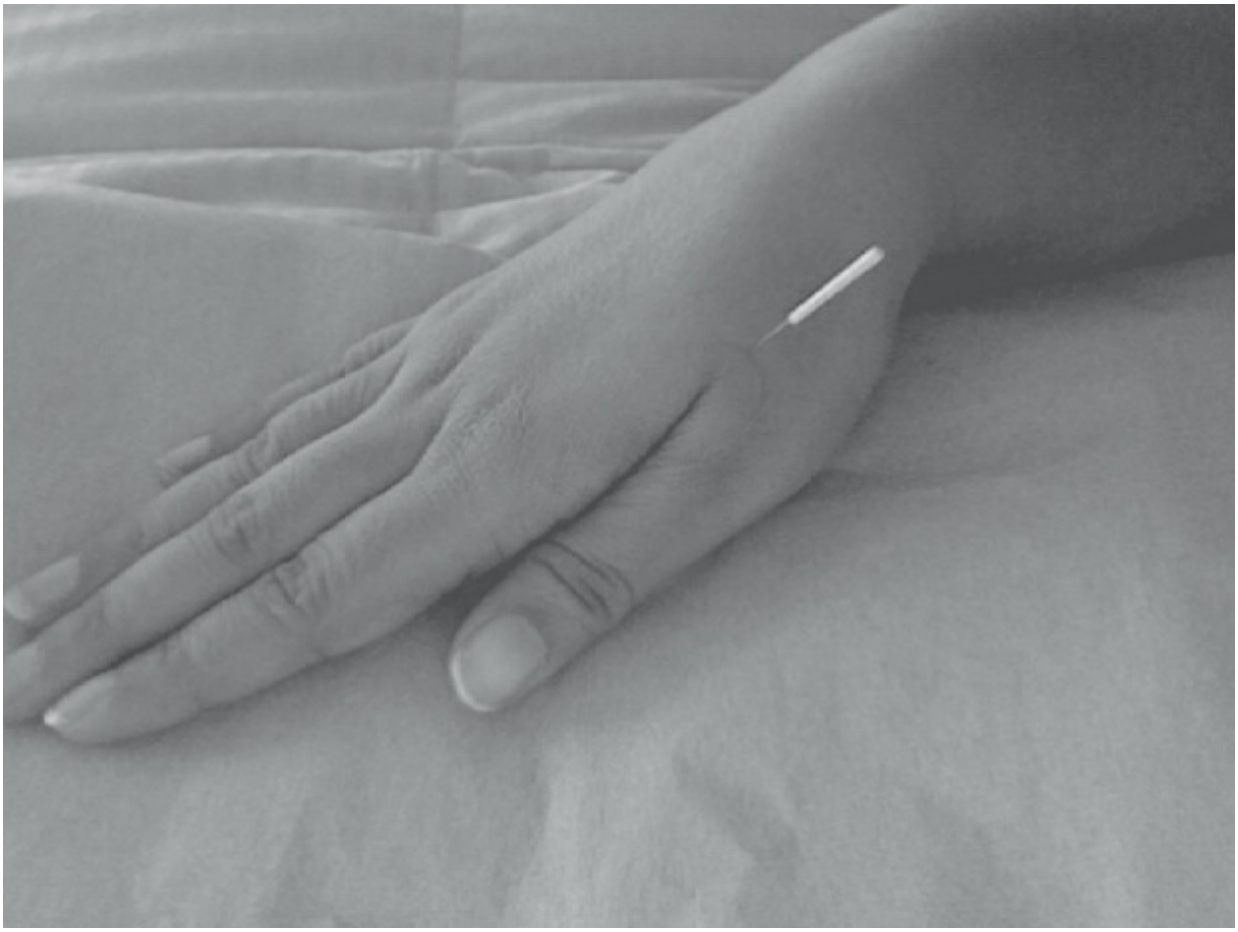

**Figure 245.1.** Acupuncture at the LI 4 point.

For a simple approach to acupuncture for labor analgesia there are two points which are commonly used:

**LI 4 (Hegu):** This point is located at the base of the anatomical snuff box—on the dorsum of the hand, between the first and second metacarpals, approximately in the middle of the second metacarpal bone on the radial side (Fig. 245.1). The needle is inserted to a depth of 0.5 cm.

**SP 6:** This point is located on the spleen meridian and is an empirical point located about one hand-breadth above the medial malleolus. It is especially useful in difficult labor. It may also aid in cervical dilatation. It is needled with a perpendicular or oblique proximal insertion.

Acupuncture is relatively low risk but is not without complications, including the risk of infection and damage to underlying structures such as the pleura, bowel, and nerves, depending on point location.

## TAKE HOME POINTS

- Many women can't or won't consider epidural analgesia for labor. This is sometimes caused by a previous negative experience.
- Women are informed consumers of labor analgesia—assume that your patients would have read about and talked to women who have received a number of different complementary and alternative treatments for labor pain. Many of these treatments will provide only low-level relief.
- Remifentanil PCA, nitrous oxide, and acupuncture may all be welcome alternatives to labor analgesia for some women.
- Remifentanil is given in small boluses as a PCA modality. Risks include maternal hypoventilation and death, and fetal bradycardia and respiratory depression.
- Nitrous oxide is given via mask at the start of a contraction. The patient must be able to hold the mask herself. Scavenging of waste nitrous oxide is required. Risks include hypoventilation and desaturation between contractions, unknown fetal sequelae, and risks to the exposed hospital staff.
- Acupuncture is a modality that is now firmly established within the confines of Western medicine especially as a complementary technique. Two points that are of special efficacy for the laboring parturient are the hand point **LI 4 (Hegu)** and the ankle point **S6.**
- Make sure you have posed the appropriate questions about these modalities to your institution before the patients pose them to you. You don't want a patient to come in and tell you about what's new in labor analgesia.

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# Epidural Labor Analgesia: Does It Prolong Labor?

Remigio A. Roque, MD and Brandon Michael Togioka, MD

Epidurals are a popular and effective choice in the management of labor pain. Various forms of neuraxial analgesia have been used in childbirth since the late 19th century. One of the first described neuraxial anesthetics involved intrathecal injection of cocaine to produce total anesthesia of the lower body. Since that time, the practice has evolved greatly. Advancement in both technique and local anesthetic formulations has provided safer, better-controlled, and more effective epidurals, a fact reflected in their increased use. However, despite their popularity and common use, several questions remain. How do epidurals affect the progression of labor? Do epidurals increase the rate of cesarean and instrumental delivery? Does it matter when epidural analgesia is administered or what concentration of local anesthetic is used?

Labor is defined as regular uterine contractions that bring about demonstrable effacement (i.e., thinning) and dilatation of the cervix. While it is not usually difficult to determine if someone is in labor, it can be quite hard to know exactly when labor started and thus challenging to determine the duration of labor. Labor is defined by three stages. The first stage of labor encompasses the period of cervical effacement and dilatation. It can be further divided into two phases—a latent phase, in which regular uterine contractions start to cause cervical thinning and dilation, and an active phase when the rate of cervical dilation speeds up. Previously, the transition from latent to active labor in the United States was set at 4 cm, but in an effort to decrease the number of cesarean sections called for failure to progress, the transition point was moved to 6 cm. The active phase of the first stage of labor ends when the cervix has fully dilated to 10 cm. The second stage of labor encompasses the period of fetal expulsion—beginning when cervical dilatation is complete and ending with delivery. The third stage of labor encompasses the time following delivery during which there is placental separation and expulsion.

Determining the impact of epidurals on the stages of labor is difficult. There is a clear association between the use of neuraxial anesthesia and prolonged labor, cesarean

delivery, and instrumental vaginal delivery (i.e., using a vacuum or forceps to deliver a baby). However, a causal relationship is not clear. The unpredictable and individualized nature of labor makes it difficult to design and perform randomized controlled trials (RCTs). Ideally, an RCT studying the effect of epidurals on labor would contain a control group that did not receive any analgesia, a requirement that would not get IRB approval. Additionally, study groups are hard to maintain as crossover rates are high—both from the control group to the epidural group (e.g., worsening pain, dystocia) and from the experimental group to the control group (e.g., rapid labor that does not allow time for an epidural). Double-blinding is also near impossible as epidurals have repeatedly been shown to offer superior pain control and often some degree of leg weakness making it fairly obvious which intervention a patient has received. To this extent, there may not be a definite answer with regard to the effect of epidurals on labor, but there is still much that we can tell our patients.

There are no RCTs examining the effect of labor epidurals in which the primary outcome is the duration of the first stage of labor. When RCTs looked at the duration of the first stage of labor as a secondary outcome prolongation was generally seen. While the mechanism for epidurals prolonging the first stage of labor is still unknown many experts believe it has to do with an imbalance in the autonomic nervous system. It is postulated that epidural analgesia may slow labor by blocking parasympathetic (labor-promoting) outflow without fully interrupting the sympathetic (tocolytic) innervation to the uterus. At this point, it can only be said that epidurals may prolong the first stage, and the effect is likely to be modest—around 30 minutes.

In contrast, there is little doubt that epidural analgesia extends the second stage of labor. The American College of Obstetrics and Gynecology (ACOG) allows for an extra hour of pushing to occur in patients who have received an epidural before diagnosing a prolonged second stage of labor. Similar to studies on the first stage of labor, it is impossible to complete an ideal study on the second stage of labor. In an ideal study, the epidural would be placed at 10-cm dilatation so as not to have a carryover effect from the first stage, there would be a control group without any analgesia, and oxytocin usage would be kept similar between study arms. Again, despite imperfect science it appears that the average prolongation is around 15 minutes when compared to patients receiving systemic opioids. The mechanism behind this protraction is not known, but several possibilities have been suggested. It may be that having complete analgesia during the second stage decreases maternal pain to the point that it decreases the urge to bear down and push. Additionally, if high concentrations of local anesthetic are used in the epidural the abdominal and pelvic floor musculature are weakened leading to impaired maternal expulsive efforts and impaired fetal rotation during descent. The delay in second stage has not been shown to be harmful to either

mother or baby as long as routine monitoring and labor management are continued.

With respect to the last stage of labor, epidurals do not increase the time for delivery of the placenta. In situations of spontaneous or expressed placental delivery, there appears to be no difference in the duration of the third-stage labor. However, in cases where manual extraction is required, use of epidural anesthesia shortens the process by several minutes. It may be that use of epidurals in these cases provides a permissive effect, allowing providers to intervene earlier under the safeguard of good perineal analgesia.

With these aforementioned consequences of epidural use on labor progression, it would be reasonable to presume that epidurals might also impact the mode of delivery. The first studies on this topic showed an association between neuraxial anesthesia and increased rates for both instrumental and cesarean delivery. As previously discussed, optimal studies are hard to design and are limited by several factors. In this case, the association of dystocia (difficult labor) with higher rates of cesarean and instrumental delivery cannot be overlooked. The intensity of labor pain has been shown to impact the rate of cesarean delivery. Lower rates of spontaneous vaginal delivery and higher rates of cesarean delivery have been observed in women who required higher doses of IV analgesia throughout their labor. Additionally, these women rated their pain subjectively higher prior to the administration of analgesia, and the indication for progressing to cesarean section was more often for dystocia. It has also been observed that women with more breakthrough pain, despite receiving epidurals, are at increased risk of operative delivery. To this extent, a request for an epidural may serve as a marker for the severe pain associated with dystocia, which is itself a risk factor for having a cesarean or instrument-assisted delivery.

No RCTs have been designed to specifically look at the effect of epidural analgesia on the rate of instrumental delivery as a primary outcome. Furthermore, most studies that have been completed do not define the criteria used for proceeding with instrumental delivery, making it difficult to discern if obstetrician bias may have effected the decision to use forceps or a vacuum. The available data are conflicted, with some studies showing increased rates of instrumental delivery with an epidural and others showing no difference. This discrepancy may be explained in part by differences in the concentration of local anesthetic used. Epidurals with higher concentrations of local anesthetic produce a denser block that results in more complete analgesia in the second stage which can decrease the urge to push. Higher local anesthetic concentrations will also cause more abdominal and perineal muscle weakness which can slow down fetal descent. Thus, it is not surprising that studies involving epidurals containing higher concentrations of local anesthetic are more likely to show that epidurals increase the rate of instrumental delivery.

The question pregnant women are often most interested in is whether epidurals increase their chances of having a cesarean section. Early studies demonstrated significant increases in the rate of cesarean delivery when women were given an epidural. However, large meta-analyses have since shown this not to be true. Initial studies also suggested that the risk of cesarean was higher when epidurals were administered during the latent phase of the first stage of labor (i.e., at a cervical dilation less than 4 cm). As a result, previous statements by ACOG recommended for practitioners to delay administration of epidural anesthesia until cervical dilatation reached 4 to 5 cm. Multiple well-conducted studies have now shown that early epidurals (i.e., epidurals placed before a woman is 4 cm dilated) do not increase a woman's risk of having a cesarean section. ACOG has since adjusted its statement, concluding that:

**"Neuraxial analgesia techniques are the most effective and least depressant treatments for labor pain."**

**"There is no other circumstance where it is considered acceptable for an individual to experience untreated severe pain, amenable to safe intervention, while under a physician's care. In the absence of a medical contraindication, maternal request is a sufficient medical indication for pain relief during labor."**

**"The fear of unnecessary cesarean delivery should not influence the method of pain relief that women can choose during labor."**

## TAKE HOME POINTS

Epidurals are a popular, safe, and effective choice for managing labor pain.

- There are clear associations between use of neuraxial anesthesia and both prolongation of labor and higher rates of instrumental and cesarean delivery. It is very difficult, however, to make causal statements regarding these effects.
- Epidural use may prolong the first stage of labor by 30 minutes and the second stage of labor by 15 minutes. This delay by itself has not been shown to worsen maternal or fetal outcomes.
- If manual extraction of the placenta is needed, having an epidural makes the process faster.
- The request for an epidural may serve as an indicator of dystocia which by itself increases a woman's chances of having an instrumental or cesarean delivery.
- Epidurals may increase the rate of instrumental delivery. The effect of an epidural on risk for instrumental delivery is likely dependent upon the concentration of local anesthetic run through the epidural.
- Epidural use does not impact the rate of cesarean delivery, regardless of when it is administered.

- According to ACOG, maternal request is a sufficient indication for pain relief during labor in the absence of other medical contraindications.

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# We Were Taught Once a C-section, Always a C-Section … What to Do When Your Hospital Now Wants to Provide Trial of Labor After Cesarean (TOLAC) Services

Jordan B. Johnson, MD and James S. Hicks, MD MMM

Providing anesthesia services in the obstetric setting is a necessary and virtuous endeavor. The peripartum period for women is a time filled not only with intense emotional experiences but also with decisions regarding their birth process and the medical implications of labor and delivery. For many women and their families the peripartum period is straightforward, allowing for a pleasant patient–anesthesia provider relationship involving primarily labor analgesia. However, for some patients, personal preference and medical risk factors influence the patient–anesthesia provider relationship to an unexpected and significant degree. These outside-the-average situations can involve consideration of surgical anesthesia and resuscitation and even force the clinical and administrative reviews of each hospital's capability to provide certain services.

The marketing of hospital services has become an increasingly obvious phenomenon in recent years. Obstetric services in particular have often held the spotlight given their potential to produce happy patients and multigenerational allegiance. Posh facilities with luxurious amenities, excellent anesthesia coverage, and "walking" epidurals typify the lengths to which hospitals go to attract patients. Increasingly, the ability to provide a trial of labor to patients who have had a previous cesarean section (TOLAC) has become another service that administrators (and sometimes, but not always, obstetric providers) wish to offer. Recent published work has shown that, in certain high-risk populations of women who had a previous cesarean section, over 80% of them elected to have a repeat cesarean section. But, of course, this means that up to 20% of these high-risk, previous cesarean patients choose to undergo a trial of labor. **Importantly, only two-thirds of these patients attempting a high-risk trial of labor were successful, at having a vaginal birth after cesarean (VBAC).**

The most recent practice bulletins for TOLAC issues by the American Congress of Obstetricians and Gynecologists were in 2010. These bulletins emphasize ACOG's recommendations regarding the patients for whom TOLAC is appropriate as well as risk factors for an unsuccessful trial. ACOG strongly recommends (level A) that most women who have had a single previous low **transverse** cesarean delivery should be offered and counseled regarding TOLAC and VBAC. They also identify multiple other clinical risk factors for decreasing the likelihood of a successful TOLAC, with which

anesthesia providers should be familiar: multiple previous cesarean deliveries, fetal macrosomia, >40 weeks of gestational age, previous low **vertical** incision, maternal obesity, non-white ethnicity, short interpregnancy interval, and pharmacologic induction with prostaglandins. There must be a system in place for identification and recognition of these factors in patients attempting TOLAC so as to be prepared to provide surgical anesthesia in a safe and timely manner. **This is necessary because a greater risk of major maternal morbidity, including uterine rupture, associated with TOLAC is most often manifested at the time that TOLAC has failed and a repeat cesarean delivery is required.**

TOLAC is one example of a clinical scenario at the focus of a joint statement from both the American Society of Anesthesiologists (ASA) and ACOG. They recognized the need to have established Optimal Goals of Anesthesia Care in Obstetrics, originally published in 2007 and amended in 2010. These goals are summarized as follows:

) A credentialed anesthesia provider needs to be available to administer an obstetric anesthetic when necessary.

) A credentialed anesthesia provider needs to be available at any time to support vital functions in the event of an obstetrical emergency.

) Credentialed anesthesia and surgical providers need to be available to begin a cesarean delivery within 30 minutes of the decision to do so.

) Because of the increased risk of major morbidity (e.g., uterine rupture) associated with TOLAC, appropriate facilities and personnel should be immediately available, and when these are deemed not immediately available the decision to move forward with TOLAC should only be made after the patient has been informed of the risks.

) An appointed physician in anesthesia should be readily available for all anesthetics administered.

For larger centers having high obstetric volumes, the requirement for immediate availability is often easily met by current practice in which anesthesia and obstetric providers are always in-house. For lower volume facilities, however, maintaining immediately available anesthesia and obstetric capabilities over the course of an extended labor can prove practically and financially infeasible. Language in Optimal Goals of Anesthesia Care in Obstetrics is not prescriptive for the manner in which such hospitals elect to meet these recommendations, acknowledging that individual circumstances must dictate when a TOLAC approach is safe and practical.

## TAKE HOME POINTS

- Many women who have had a previous low transverse cesarean section can have a successful trial of labor resulting in vaginal delivery, and may choose this as their preferred labor method.
- Hospitals should remain sensitive to requests by individual patients for TOLAC and attempt to accommodate these requests whenever possible.
- Certain risk factors should be identified that predispose patients to having a failed TOLAC, which carries a higher risk of major morbidity.
- The decision by hospitals and patients to attempt a TOLAC should be made only after both parties understand the individual hospital's capability to fulfill the provisions in Optimal Goals of Anesthesia Care in Obstetrics.
- One of the staples of a well-functioning obstetric anesthesia program is the ability of qualified anesthesia providers to work alongside the obstetric physicians and nurses to timely provide surgical anesthesia.
- In addition, the teamwork approach involving coordinated identification of patients with risk factors which increase the likelihood of requiring surgical anesthesia is paramount.

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# Should We Place a Spinal for a Version? Anesthesia for External Cephalic Version

Angela Pennell, MD and Brandon Michael Togioka, MD

Breech presentation affects 3% to 4% of term pregnancies. Because a fetus is more likely to be safely delivered vaginally from the vertex position, external cephalic version (ECV) is a technique used by obstetricians to change the presentation of the fetus from breech to vertex. The procedure is performed as follows: The obstetrician will apply something over the abdomen (corn starch or gel) to facilitate smooth sliding of their hands over the patient's abdomen. The obstetrician will then place their hands behind the mother's pubic symphysis to pull the baby out of the pelvis. The obstetrician will then attempt to change the baby to a head down position through either a forward or backward somersault. Periodic assessment of fetal well-being either with ultrasound or a Doppler is performed every few minutes. The obstetrician may make multiple attempts at successful version, but their efforts are usually limited to no more than a few attempts. Significant fetal bradycardia and substantial patient discomfort (important for anesthesia) are signs that the ECV should be abandoned. Every attempt at an ECV is essentially a balancing act between the potential advantages allotted from a vaginal delivery and the risks of placental abruption, cord prolapse, rupture of membranes, and fetomaternal transfusion (i.e., fetal blood cells coming into contact with the maternal circulation).

Depending upon the study, the success rate from ECV is quite variable from as low at 16% to as high as 100%, with success rates of 50% to 60% commonly quoted to patients. Both obstetric and anesthesia staff acknowledge that the success of an ECV may depend to a considerable degree on the skill and experience of the obstetrician combined with the level of pain tolerated by the patient. That being said, the following factors may be associated with higher rates of ECV failure: maternal obesity, nulliparity, advanced cervical dilation, low station (i.e., a baby that has descended further into the pelvis), and an anterior placenta.

The question of whether neuraxial anesthesia (spinal or epidural) facilitates successful ECV has been controversial. However, there is now accumulating evidence

that neuraxial anesthesia likely improves the chance for a successful ECV. There are several prospective trials, retrospective studies, and meta-analyses that have investigated this topic. A Cochrane review from 2015 showed that ECV was more successful when neuraxial anesthesia was combined with a tocolytic versus tocolytic alone. A very recent meta-analysis by Magro-Malosso et al. in the American Journal of Obstetrics and Gynecology found a statistically significant increase in the rate of successful ECV when neuraxial anesthesia was used. Despite these findings, a February 2016 American College of Obstetricians and Gynecologists Practice Bulletin recently stated: "data are insufficient to conclusively…make a recommendation favoring spinal or epidural anesthesia during ECV attempts." In this manner, the rate of neuraxial blockade for ECV was found to be quite variable across the country with some hospitals noting use of neuraxial anesthesia for all attempts while others stated they never used neuraxial anesthesia for ECV.

We believe some of the controversy may be because studies involve different local anesthetic types and concentrations. Interestingly, in the above-mentioned meta-analysis by Magro-Malosso et al., the studies that showed no benefit from neuraxial anesthesia used less dense blocks than the studies that showed benefit. The denser blocks may have allowed for more abdominal muscle relaxation and less maternal pain leading to less guarding and a higher rate of ECV success.

So one may ask, why not give everyone a dense block? Well, some obstetric providers hold the belief that a dense neuraxial block can mask the pain that sometimes accompanies a placental abruption leading to delayed recognition and potentially a worse fetal outcome. Furthermore, removing pain as a limiting factor in the procedure may also increase the potential for a greater number of maneuvers and more aggressive attempts. In addition, neuraxial anesthesia carries its own risks: hypotension, infection, paresthesias, bleeding/epidural hematomas, and postdural puncture headaches.

If you are told about an ECV, the first question that you should ask is the gestational age of the mother, as this will greatly affect your anesthetic plan. The American College of Obstetricians and Gynecologists recommends offering an ECV to women starting at 37 weeks of gestation. Thirty-seven weeks is recommended because the baby is full term (in case of complications necessitating an emergent cesarean section) and if the ECV is successful a spontaneous reversion back to breech presentation is less likely at later gestations. In addition, amniotic fluid seems to peak at around 34 weeks and some studies show higher rates of ECV success with larger amniotic fluid volumes. At our institution, women at 37 weeks often receive an ECV attempt in a labor room without anesthesia involvement. Women can request a spinal for ECV at 37 weeks, but this decision shifts their procedure to the operating room and significantly prolongs their time in the hospital. For these reasons, most women elect for an anesthesia-free ECV at

37 weeks. If the 37-week attempt is unsuccessful, women are offered a second attempt at 39 weeks with combined spinal–epidural anesthesia in the operating room. If the 39-week attempt is successful, the pregnant mother is moved to the labor floor and uses the epidural for analgesia. If the ECV is unsuccessful, we proceed with a scheduled cesarean section. In both cases, tocolysis with terbutaline is considered as ECV success rates have been shown to be higher with tocolysis than without.

Any time an ECV is performed, with or without a block, it is prudent to be prepared for an emergent cesarean section. For this reason, ECVs should generally be performed during the daytime when staffing levels are higher and all patients having an ECV require peripheral intravenous access. Remember to have a nonparticulate antacid such as citric acid/sodium citrate, a device to provide left uterine displacement, a smaller-diameter endotracheal tube, and emergency airway equipment available. Most of the time when anesthesia is not on board at the time of a called emergent cesarean section, general endotracheal intubation is necessary; however, it is always worth having a conversation with the obstetricians and potentially checking one last fetal heart rate before proceeding with a cesarean section under general anesthesia.

## TAKE HOME POINTS

- ECV is typically performed in term parturients and has a highly variable success rate.
- Always prepare for an emergent cesarean section when an ECV is being performed, regardless of whether anesthesia will be utilized. We will say this again—don't assume that an ECV proceeding to an emergent operative delivery is a theoretical concern only. It isn't. For this reason, even if there isn't a plan to perform neuraxial anesthesia for the ECV, many institutions have a practice policy that mandates placing decent IV access before starting the ECV procedure. The editors have also trained and worked at institutions that would only undertake ECV if the anesthesia staff was observing the procedure or in the immediate vicinity.
- There is accumulating evidence that neuraxial anesthesia facilitates successful ECVs. Widespread adoption of ECVs under regional anesthesia has been hindered by concerns that neuraxial anesthesia may mask and possibly predispose toward complications such as placental abruption.
- The decision to place a spinal or epidural for ECV should be made in concert with the obstetric team and patient after a thorough discussion of risks and potential benefits.

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# Management of an Accidental Dural Puncture in the Laboring Patient "When the Hanging Drop Becomes a Flowing River …"

Dustin McGirr, DO

A 158-kg parturient requests an epidural for labor analgesia. Painful contractions hinder the patient's ability to remain still during lumbar epidural placement. The procedure is further complicated by difficulty palpating the bony anatomy. After multiple attempts at epidural placement, you finally achieve "loss of resistance" (LOR). Following removal of the LOR syringe, cerebrospinal fluid pours out of the Tuohy needle. What are your options for providing labor analgesia in the setting of an accidental dural puncture (ADP)? What are the specific risks and potential benefits in providing neuraxial anesthesia following an ADP?

An accidental dural puncture (ADP) complicates ~1% of epidural placements in laboring patients. Following recognition of a dural puncture, the practitioner has two options: (1) replace the epidural catheter at the same or (preferably) alternative interspace; or (2) provide continuous spinal analgesia through a catheter threaded into the subarachnoid space. **The most appropriate management of an ADP in a laboring parturient is currently unclear.** In a recent survey of North American obstetric anesthesiologists, 75% of respondents reported replacing the epidural following an ADP; whereas, 25% placed an intrathecal catheter.

Concerns involving central nervous system (CNS) infections and neurotoxicity have hindered universal acceptance of continuous spinal analgesia. Placing a catheter into the intrathecal space provides a direct conduit from the outside environment to the CNS, theoretically increasing the risk of both neurologic infection and injury. In 1992, the United States Food and Drug Administration mandated the withdrawal of intrathecal microcatheters (27G or smaller) due to several cases of cauda equina syndrome. Subsequent investigations suggested that the neurologic injury was a result of direct CNS exposure to large doses of concentrated local anesthesia, specifically, greater than

100 mg of 5% hyperbaric lidocaine. The slow flow rate of hyperbaric solutions through small-bore catheters likely resulted in the pooling of highly concentrated local anesthesia onto nerve roots in the sacral area.

More recently, Arkoosh et al. demonstrated that intrathecal catheters can be used safely and effectively in the parturient. Labor analgesia was provided for 329 parturients using a combination of isobaric bupivacaine (0.25%) and sufentanil (5 mcg). No CNS infection or permanent neurologic changes were reported. Patients receiving continuous intrathecal analgesia reported higher maternal satisfaction, less motor blockade, and earlier ambulation.

In addition to the benefits demonstrated in Arkoosh et al.'s study, there are several other reasons to consider placement of an intrathecal catheter in the setting of an ADP. Spinal anesthesia offers more rapid onset (2 to 3 minutes versus 10 to 15 minutes for epidural analgesia) and greater control of analgesia. An intrathecal catheter avoids the risk of a patchy or unilateral block which may occur with a labor epidural. In addition, the lower dose requirement of local anesthesia used in spinal anesthesia virtually eliminates the risk of toxic systemic effects. Furthermore, refraining from subsequent epidural attempts obviously avoids the risk of additional dural punctures, especially in patients with lumbar anatomy that is abnormal or difficult to palpate. Finally, evidence from several sources report a small but significant decrease in postdural puncture headache rates with intrathecal catheter placement in the setting of an ADP.

**Table 249.1 ■ Suggested Patient-Controlled Spinal Analgesia (PCSA) Settings**

| **Local Anesthetic** | | | |
|---|---|---|---|
| | Loading Dose (mg) | Infusion (mg/hr) | Bolus (mg) |
| Bupivacaine | 1.0–3.0 | 0.5–3.5 | 0.5–1.25 |
| Ropivacaine | 2.0–4.0 | 1.0–4.0 | 1.0–2.0 |
| **Opioid** | | | |
| | Loading Dose (mcg) | Infusion (mcg/hr) | Bolus (mcg) |
| Fentanyl | 10–20 | 2–10 | 2–5 |
| Sufentanil | 1–5 | 1–5 | 1–2 |

Vigilance must be exercised in the management of a spinal catheter. Placement of a catheter in the intrathecal space allows direct contact with components of the CNS. As such, the catheter should be threaded into the subarachnoid space a distance of only 2 to 3 cm. Spinal analgesia can be initiated and maintained with a combination of low-dose isobaric local anesthesia and/or lipophilic opioids (Table 249.1). After a loading dose, the infusion should be initiated at a low rate and gradually titrated to the patient's analgesic requirements. The patient-controlled spinal analgesia (PCSA) function can be disabled or set to a conservative lockout rate (i.e., small boluses every 30 minutes).

Avoiding unnecessary disconnections of the infusion system minimizes the risk of contamination and drug error. The catheter and pump should be clearly labeled, so that all healthcare providers are aware the catheter is located in the intrathecal, not epidural, space (Fig. 249.1). Finally, the sensory level and intensity of motor blockade should be monitored frequently to avoid inadvertent high spinal anesthesia.


**Figure 249.1.** Proper labeling of the catheter, infusion tubing, and pump following placement of an intrathecal (aka "spinal") catheter.

If the practitioner elects to replace the epidural rather than use an intrathecal catheter, additional care must be exercised. Local anesthesia or opioids injected through the epidural catheter may pass through the dural puncture site and into the subarachnoid

space. Epidural boluses should be initially limited to 5 mL to avoid an unexpected high neuroblockade. Regardless of whether an epidural or intrathecal catheter is used following an ADP, it is important to recognize that a complication, albeit common, has occurred. As such, the patient's post-delivery course should be followed closely and documented in their medical record.

## TAKE HOME POINTS

- Intrathecal catheters can be used safely and effectively after ADP.
- Intrathecal catheters and pumps should be clearly labeled to avoid being misidentified as epidural.
- Benefits of continuous spinal anesthesia include rapid onset, uniform distribution of intrathecal medications, and avoidance of additional ADPs.
- Potential risks of intrathecal catheters include CNS infection, CNS injury, and inadvertent high motor blockade.
- There is the potential for epidural medications to diffuse into the intrathecal space following an ADP.

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# "We Have an Urgent C-Section!" The Pitfalls of Intrapartum Monitoring of the Fetus

Richard C. Month, MD FASA

You are approached by the on-call obstetrician who states she must proceed with an urgent Cesarean delivery for one of the patients on the labor floor. The patient is a 29-year-old $G_2P_{1001}$ at term. She has been laboring for more than 9 hours and is on a magnesium infusion for severe preeclampsia. Her magnesium level is therapeutic. Continuous fetal monitoring shows:

**Baseline:** 110 beats per minute
**Variability:** Minimal
**Accelerations:** Absent
**Decelerations:** Persistent late decelerations

The obstetrician states that due to the poor fetal heart rate tracing an urgent Cesarean delivery is indicated, and that any delay may harm the fetus. While you proceed with the delivery, you ask yourself the following:

) What is the likelihood that this neonate will require resuscitation in the delivery room?
) Does the fetal heart tracing above truly require an urgent delivery?
) Can any of the intrapartum interventions attempted cause detrimental-appearing changes to the fetal heart rate tracing?

## Introduction

There are approximately 100 million attended births worldwide each year. Of these, 10% of neonates will require some resuscitative effort, and 1% will require intensive support. Since the anesthesiologist may, in many circumstances, be the most available critical care-trained physician to the neonate at the time of delivery, identifying the neonates at risk for resuscitative need is extremely important. Thus, it is hoped that effective monitoring of the fetus will identify those neonates at risk.

The current gold standard in intrapartum evaluation of the fetus is electronic fetal

heart rate monitoring (FHR), also known as cardiotocography. This combines monitoring of the fetal heart rate with monitoring of the uterine contractions. Monitoring the fetal heart rate and its response to uterine contractions correlates highly with well-appearing neonates. That is, a "reassuring" FHT carries a 90+% correlation with a 5-minute Apgar score greater than 7. However, due to treatment and medication interactions, limits of the examination, and normal variation between infants, the false positive rate is as high as 50%.

## Basics of Fetal Heart Rate Monitoring

Fetal heart rate monitoring consists of a continuous measurement of both the fetal heart rate and the strength and timing of uterine contractions. These two measurements are graphed together and described in terms of four parameters: **baseline, variability, accelerations,** and **decelerations.** In combination, a final determination is made regarding the status of the fetus, and interventions are taken.

## Baseline

Fetal heart rare baseline is an attempt to measure the fetal heart rate while ignoring accelerations and decelerations (described later). It is defined as the mean fetal heart rate in any 10-minute window. It is typically rounded to the nearest 5 beats per minute. **Normal** baselines range from 110 to 160 beats per minute, with higher heart rates considered fetal **tachycardia** and lower heart rates considered fetal **bradycardia**.

## Variability

Variability is a measure of the normal interplay between the immature fetal sympathetic and parasympathetic nervous system. It is a measure of fluctuations in the baseline fetal heart rate both in amplitude and frequency measured over a 10-minute window. Normal, or **moderate**, variability is fluctuation from 6 to 25 beats per minute from baseline. Fluctuations more pronounced than this are called **marked**, while detectable fluctuations less than this are called **minimal**. Undetectable fluctuations are called **absent**.

## Accelerations

Fetal heart rate accelerations correlate well with fetal central nervous system wellbeing. They are defined as a visually apparent abrupt increase in fetal heart rate of at least 15 beats per minute for at least 15 seconds for a fetus of 32 weeks of gestation or older.

## Decelerations

Decelerations are the most watched component of fetal heart rate tracings. They are defined much as an acceleration: a visually apparent abrupt decrease in fetal heart rate of at least 15 beats per minute for at least 15 seconds. They are further defined morphologically as follows.

**Early Decelerations:** Usually symmetrical, gradual decrease and return of the FHR. The nadir of deceleration occurs at the same time as the peak of the contraction. Associated with fetal head compression and a fetal vagal response. **Usually considered benign**.

**Late Decelerations:** Usually symmetrical, gradual decrease and return of the FHR. The nadir of the deceleration occurs after the peak of the associated contraction. Associated with a fetal chemoreceptor response to acidosis, secondary to uteroplacental insufficiency. **Always considered pathologic**.

**Variable Decelerations:** Abrupt decrease in FHR, with equally abrupt return to baseline. When associated with contractions, onset, depth, and duration will vary with successive contractions. Associated with a fetal baroreceptor reflex, secondary to umbilical cord compression, causing an increase in fetal systemic vascular resistance. May be benign or pathologic depending on the situation.

**Prolonged decelerations**, like prolonged accelerations, are between 2 and 10 minutes in length; any acceleration or deceleration of more than 10 minutes is considered a change in baseline. **Intermittent** decelerations occur with less than half of the contractions over a 20-minute period, while **persistent** decelerations occur with half or more.

## Pitfalls With FHR Monitoring

### Inter-observer Variability

All fetal heart rate measurements are done with some degree of subjectivity. In an effort to decrease this effect, a three-tiered system was developed to group fetal heart tracings into meaningful categories. These categories are outlined below.

| | Description | Interpretation |
|---|---|---|
| Category I | Must include ALL of the following:<br>• Baseline: Normal<br>• Variability: Moderate<br>• Accelerations: Present or absent<br>• Decelerations: Absent, | Normal, or reassuring. Associated strongly with fetal wellbeing and normal fetal acid–base status |

| | | |
|---|---|---|
| | except early decelerations may be present | |
| Category II | Include all tracings not identified as Category I or Category III. These account for the vast majority of fetal heart rate tracings. | Indeterminate, equivocal, suspicious, or atypical. Not immediately predictive of positive or negative fetal acid–base status. Per guidelines, "such tracings require constant reevaluation and surveillance." |
| Category III | Either:<br>• Absent variability with any of the following:<br>  • Recurrent late decelerations<br>  • Recurrent variable decelerations<br>  • Fetal bradycardia<br>  • Sinusoidal pattern (FHR with a sine-wave like undulating pattern of 3–5 cycles per minute lasting 20 minutes or more. | Abnormal or nonreassuring. Associated strongly with fetal acid–base abnormalities at the time of observation. Efforts to resolve the acid–base disturbance, up to and including urgent delivery, should be taken immediately. |

Even with the three-tiered system, inter-observer variability is still a significant problem, as each tier is directly dependent on a combination of observations all of which are associated with varying degrees of variability; poor inter-observer correlation is noted with fetal bradycardia, decreases in variability, recurrent and/or prolonged decelerations, and variable decelerations. This is a likely cause of the large number of false positive fetal heart rate tracings.

## Effects of Treatment on the Fetal Heart Rate

Many of the interventions, specifically medications, undertaken through the course of labor and delivery are associated with changes in the fetal heart rate. Most medications readily cross the placenta and thereby have a direct effect on the fetus. **Magnesium acts as a central nervous system depressant and readily crosses the placenta. This**

**causes a decrease in fetal heart rate, a reduction in variability, and a loss of accelerations if previously present. These would cause deleterious-appearing changes to the fetal heart rate tracing without worsening fetal outcome or indicating fetal acidosis.** Similar effects are noted with opioids, benzodiazepines, and certain classes of antiemetics.

Conversely, certain drugs may affect fetal acid–base status iatrogenically, while not indicating a perfusion issue and not leading to poor fetal outcomes. These include ephedrine, atropine, and scopolamine, all of which readily cross the placenta. All three may contribute to fetal tachycardia, and atropine has been shown to eliminate fetal heart rate variability.

## Conclusion

While FHR monitoring has become the gold standard in intrapartum fetal monitoring, it is not without significant concerns for error and misinterpretation. Interpretation of fetal heart tracings should therefore never be made without consideration of other fetal and maternal factors, nor should it be made without understanding of its limitations.

### TAKE HOME POINTS

- The current gold standard in intrapartum evaluation of the fetus is electronic fetal heart rate (FHR) monitoring. Normal, or reassuring, FHT carry a 90+% correlation with a 5-minute Apgar score greater than 7. However, the false positive rate is as high as 50%.
- Fetal heart rate monitoring consists of a continuous measurement of both the fetal heart rate and the strength and timing of uterine contractions. These two measurements are graphed together and described in terms of four parameters: **baseline, variability, accelerations,** and **decelerations.** In combination, a final determination is made regarding the status of the fetus, and interventions are taken.
- All fetal heart rate interpretations are subject to significant inter-observer variability. In an effort to decrease this, FHR tracings are grouped into Category I (normal/reassuring), Category II (indeterminate), and Category III (abnormal/non-reassuring). Even with these categories, large inter-observer variability persists. Nonetheless, anesthesia providers should be knowledgeable and practiced in interpreting the FHR tracing and should do so as part of the basic provision of care.
- Numerous common medications and interventions can affect the fetal heart tracing in ways that appear deleterious, but may, in fact, be benign.

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# Stat C-Section—The 30-Minute Rule and Beyond

Karen Hand, MB BS FRCA and Christopher E. Swide, MD

Nearly one-third of all births in the United States today are by Cesarean section (C-section), a dramatic increase from 5.5% of births in 1970. Traditionally, these deliveries have been classified "elective vs. urgent." A considerable number of C-sections fall into the urgent, or even emergent, category. It is imperative that the anesthesiologists caring for these patients understand that the parturient presenting for non-elective C-section brings with her unique anesthetic challenges. It is also imperative that we understand that the health, safety, and well-being of the mother always take priority over that of the fetus.

In some cases both the mother and the baby are equally in jeopardy, however, in many cases there is an increased threat to either the well-being of the mother or to the well-being of the fetus alone. Refinements to the classification system for urgency of C-section may improve communication around urgent need for delivery, and perhaps improve safety for both mother and baby.

Historically, the "30-minute rule." was adopted 25 years ago by the American Congress of Obstetricians and Gynecologists, and subsequently endorsed by other bodies such as the ASA and The Joint Commission. In the United States, the 30-minute rule mandates that obstetric units must be able to provide for a **decision-to-incision time of 30 minutes or less for urgent cases**.

Unfortunately for everybody, there is surprisingly little scientific evidence in support of the 30-minute timeline. What data there are even suggest a worse outcome for babies delivered most rapidly—although of course this probably reflects a need for the fastest deliveries for the sickest babies. There is some evidence that suggests worsened outcomes after 40 minutes or even after 75 minutes. Taken outside the clinical context, these data are hard to apply concretely to our clinical practice—75 minutes seem like an awful long interval for decision-to-incision.

On the other hand, for some babies a decision-to-incision interval of 15 minutes is too long and will result in severe fetal morbidity or mortality.

How do you devise a path of safety for your patients through these urgent and emergent situations? First of all, as we have stated elsewhere, the most skilled, experienced, and successful OB anesthesiologists know a lot about obstetrics per se. **We recommend that you become and remain comfortable in understanding and distinguishing irreversible causes of fetal compromise, such as cord prolapse, severe placental abruption, uterine rupture, and terminal fetal bradycardia.** These emergent conditions require delivery as rapidly as possible, and the inflection point on the risk–benefit ratio is at a very different point in the anesthetic care plan from scenarios such as arrest of labor or nonreassuring category II fetal heart rate tracing.

Communication between the obstetrician and anesthesiologist about the urgency of C-section can be challenging and, unfortunately, is often limited to "Have we got time for a quick spinal?" However, new classification systems may help improve communication regarding urgency. The Lucas classification system was first described in 2000. It is widely used in Europe, having been adopted by the Royal College of Obstetricians, for example. In this system there are four categories of urgency:

**Category 1:** Emergency. An immediate threat to the life of the mother or fetus.

**Category 2:** Urgent. Maternal or fetal compromise requiring prompt delivery.

**Category 3**: Needing early delivery but maternal or fetal compromise is absent.

**Category 4:** Elective. Can be scheduled at a time to suit mother and staff.

A Lucas category 1 C-section is usually understood to require general anesthesia, unless there is a labor epidural in place which can be extended rapidly, or unless general anesthesia poses an unacceptable risk to the life of the mother. For a Lucas category 2 Cesarean section it will usually be possible to avoid general anesthesia with its attendant risks.

Other similar classifications, such as the "traffic light system," have been proposed. This classification assigns green for elective and nonurgent C-sections, yellow or orange for urgent but there is some for regional anesthesia, and red for emergent operative delivery and baby needs delivery now. There are no specific data to support this system nor are we, the editors, aware of national standardization of the traffic light classification. The disadvantages of the Lucas and other systems occur because of the variability of opinion between providers as to category for particular scenarios, although in testing the Lucas system was found to achieve the most consistent level of agreement between providers.

In the United Kingdom, the National Institute of Clinical Excellence reported on the use of the Lucas classification system in 2011. It was emphasized that although units must be set up to able to deliver a fetus within 30 minutes, that is not always necessary or desirable, and that decision-to-delivery interval should be used as an audit standard rather than to judge interdisciplinary team performance for any individual C-section. A recent study apparently demonstrated improvement in neonatal outcomes with a dedicated effort to reduce the time for decisions-to-delivery intervals, but at the expense of an increase in the number of general anesthetics administered to the mother. An accompanying editorial urged caution in increasing risks to the mother.

For the anesthesiologist attempting to balance the safety of both mother and baby this is all well and good, but what do you actually DO in the various stages of obstetrical clinical emergency?

First of all, you quickly review in your mind how you would do an urgent or emergent delivery for each patient you meet on the labor deck **when you meet her.** And you ask the relevant questions such as the urgency of previous deliveries. Feel free to form opinions within your own mind as to how likely the patient is to have an uncomplicated labor and delivery—look comprehensively at your patient including her body habitus, her other medical problems, and her psychological and emotional state. **If you think you might be heading toward an urgent or emergent delivery in later hours, get the epidural in and get it working.** Secure decent IV access, this is no time to scruple about putting in an 18-gauge cannula. Keep a close assessment of where the labor block is and don't let it wear down.

For every level of clinical urgency, whether you organize it in your mind into Lucas categories or another classification (e.g., 5 minutes until incision, 10 minutes until incision, 20 minutes until incision, and so forth) you should develop and know hands-down what you are going to do. You need a tried and true method for each category.

The authors and editors have practiced OB anesthesia for many years and here are some of our own practice parameters:

- **First, never neglect standard ASA monitors**—call for help in placing these or have the nurses or medical students do this. When the case is reviewed, you do not want to spend any time explaining why the monitors weren't on. And remember, universal precautions—always!

- **Urgent operative delivery with low or medium epidural level:** 20 cc of 3% chloroprocaine after standard test dose with patient positioned on operating room table. Also, for supplementation of the "nonperfect block," we use ketamine 40- to 50-mg bolus to start, then a 10- to 20-mg bolus, titrated to nystagmus.

- **Urgent operative delivery with significant epidural labor block:** 10 cc of 3% chloroprocaine after standard test dose with patient positioned on operating room table.

- **Urgent operative delivery without epidural and when general anesthesia is contraindicated:** use spinal anesthesia with hyperbaric bupivacaine. There is a slight range of doses recommended. The editors teach and use 12 mg of 0.75% hyperbaric bupivacaine (1.6 cc) for a parturient of average height for these clinical situations. If the patient is short or there are concerns about the potential and sequelae of a high block, use 10 mg of 0.75%. This dose range should give a reliable surgical block that is familiar and relatively easy to manage. Also when minutes or seconds count, this is a quick and easy dose to draw up. Ketamine can be used to supplement as noted above.

- **The editors also use a 25-gauge Whitacre for both urgent and nonurgent spinals.** We will **occasionally** use a bigger spinal needle, such as a 22-gauge Whitacre needle, if we have assessed an increased difficulty of placement, such previous back surgery or prepregnancy morbid obesity. Keep in mind that use of a 22-gauge spinal needle for a parturient significantly increases the risk of postdural puncture headache. This risk is accepted with the view that spinal headaches can be very painful but are not dangerous in the way that a delayed emergent delivery is painful. Although larger needles are sometimes used, it should not be inferred that a 22-gauge needle is standard of care for urgent C-sections or reflective of common practice.

- **Emergent operative delivery: keep in mind that these are rapid sequence inductions!** We use etomidate 0.3 mg/kg as a mainstay of our urgent or emergent general anesthetics. For asthmatics we use ketamine 1- to 2-mg/kg induction bolus. For neuromuscular blockade, we use succinylcholine 1 mg/kg or rocuronium 1 mg/kg if succinylcholine is contraindicated. We don't use vecuronium for a stat C-section because the onset is too slow, but in the case of drug shortage or some other situation when that is the only option, we would give vecuronium 0.3 mg/kg to speed the onset of neuromuscular blockade.

It is generally agreed that the quickest way to prepare the mother for rapid delivery of the fetus is with general anesthesia. However, during pregnancy there are numerous physiologic changes which occur by the third trimester which potentially make general anesthesia more hazardous. The anesthesiologist must be familiar with the major physiologic changes that occur with pregnancy and their anesthetic implications (Table 251.1).

## Table 251.1 ■ Physiologic Changes Associated With Pregnancy

| System | Physiologic Changes at Term Gestation (Compared With Prepregnant Values) | Anesthetic Implications |
|---|---|---|
| Respiratory | 30–40% increase in oxygen consumption<br>20% decrease in FRC<br>45% increase in minute ventilation<br>Increased airway edema and mucosal friability | Rapid development of hypoxemia during apnea, potentially difficult intubation |
| Cardiovascular | 50% increase in cardiac output<br>20% decrease in SVR<br>Possible aortocaval compression by gravid uterus<br>55% increase in plasma volume<br>45% increase in blood volume | Aortocaval compression → decreased preload → hypotension in supine parturient → uteroplacental insufficiency |
| Gastrointestinal | Anatomic displacement of stomach cephalad and left<br>Decreased lower esophageal sphincter tone<br>Delayed gastric emptying<br>Increased gastric acid secretion | Increased risk for aspiration (Mendelson syndrome) |
| Nervous | Increased sensitivity to IV anesthetics<br>MAC of volatile agents reduced 15–40% | Adjust doses accordingly |
| Miscellaneous | Engorged breasts<br>Increased sensitivity to nondepolarizing MR | Difficult laryngoscope insertion, reduce dosages of NDMR |

FRC, functional residual capacity; IV, intravenous; MAC, minimum alveolar concentration; MR, muscle relaxant; NDMR, nondepolarizing muscle relaxant; SVR, systemic vascular resistance.

Data from the triennial reports into maternal mortality from the United Kingdom have **consistently** shown increased mortality in women undergoing general anesthesia in pregnancy compared with regional, with the majority of deaths attributed to anesthesia being related to the airway and difficulties with intubation and ventilation. Data from the United States from the 1990s suggested a 16.7-fold increased mortality with general anesthesia. More recent data have improved, but with mortality associated with general anesthesia still nearly double that with regional anesthesia. In addition, more recent data emphasize the risk of airway complications during emergence and recovery, with half of airway-related deaths occurring during this period.

**One final note:** These cases are also situations that call for **close and direct supervision** of the resident or fellow who might be placing the block or managing the airway. We believe that the only way a trainee can gain the judgment and experience needed to become consultants is to participate as full providers in these challenging cases. However, the senior anesthesiologist or attending must stay actively involved. This active involvement can be placing the block or allowing the resident to place the block, depending on the situation. The attending anesthesiologist is ultimately responsible for his or her decisions.

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## TAKE HOME POINTS

- The urgent or emergent C-section case is one of the highest-risk clinical situations

you will encounter in your practice, right up there with patients with ruptured aortas, epiglottitis, head trauma, and penetrating trauma. You must maintain clinical competency and currency in this area if you are an obstetrical anesthesia provider. If you do not routinely do OB anesthesia, keep in mind that you may be called to the labor and delivery deck to help in an emergent situation.

- It's okay to develop a clinical suspicion that you might be facing in an urgent or emergent section for a particular patient. Get a decent epidural and IV in before you need them and keep a close eye on them. The medical situation of the parturient will provide enough uncertainty—you don't want to be wondering if a tenuous 22-gauge IV is going to get the patient and you through an operative case.
- There are situations such as cord prolapse, severe abruption, and uterine rupture where rapid delivery is likely to be beneficial to a compromised fetus, but there are other situations where this is not clearly the case. Stay current on your OB knowledge.
- Classification of urgency of C-section may aid communication. Stay current on these, but always think about how the current classification relates to what you are actually going to do and give. The classification of the clinical situation almost always translate to a time interval—5 minutes, 10 minutes, etc. Don't ask the surgeon if you have time for a spinal, ask what is the target time for incision and then make your clinical decisions.
- Efforts to improve decision-to-incision intervals **should not come** at the cost of unnecessarily increased risk to the mother.
- The mom and the baby deserve full ASA monitors!
- Do not underestimate the potential difficulty of the airway!
- These acute situations may call for the most experienced clinician to do the airway or the block.
- Every single aspect of these clinical situations will be easier to review and discuss on a post hoc basis if the health of the mother and baby has been preserved.
- Malpractice litigation that arises from the urgent or emergent section can be especially devastating for the anesthesia provider. Unfortunately and sadly, the editors have personally talked with malpractice attorneys who actively look for cases of urgent or emergent operative delivery with poor outcomes, especially if a trainee or junior anesthesiologist made several unsuccessful attempts to initiate the anesthetic. As discussed above, it's okay to take steps to make sure that you and your staff come through safely, after doing everything medically and legally mandated and appropriate to secure the health and safety of the mother and baby.

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# Postpartum Hemorrhage: Don't Forget That Having a Baby Is Major Surgery

Alexander Y. Fu, MD and Brandon Michael Togioka, MD

Postpartum hemorrhage (PPH) (i.e., >500 mL blood loss after vaginal delivery or >1,000 mL blood loss after cesarean delivery) occurs in up to 4% of parturients and is on the rise in many developed countries including the United States and Canada. Fortunately, the maternal physiology seems to be prepared for this blood loss. At term, plasma volume is increased by 45% while red blood cell volume is increased by 20%, thereby causing dilutional anemia. For most women, this translates to an increase in blood volume of 1,000 mL to 1,500 mL. Furthermore, pregnancy is associated with a hypercoagulable state in which fibrinogen and factors VII, VIII, IX, X, and XII concentrations increase, which may help to limit blood loss. On the flip side, platelets can decrease and fibrinolysis can become accelerated in the third trimester potentially leading to more bleeding. Patients may have a chronic coagulopathy or develop an acute coagulopathy as a result of massive hemorrhage, HELLP syndrome (i.e., hemolysis, elevated liver enzymes, low platelets), acute liver failure of pregnancy, or disseminated intravascular coagulation (DIC). To this extent, one can see that pregnancy is a complex interplay of physiologic changes that influence bleeding associated with delivery.

## Uterine Atony

The number one cause of PPH is **uterine atony (i.e., a lack of uterine muscle contraction after delivery)**, making up 80% of all PPH events. Risk factors include a retained placenta, abnormal placentation, a distended uterus (e.g., multiple gestations, fetal macrosomia, polyhydramnios), chorioamnionitis, prolonged labor, and general anesthesia.

**Bimanual uterine massage** (i.e., kneading the uterus with one hand in the vagina and the other hand on the abdominal wall) is the first-line therapy for atony. It promotes uterine contraction and reduces bleeding even while the uterus remains atonic. The mainstay of pharmacologic treatment for uterine atony is **oxytocin**. Like all other medications used to treat atony, oxytocin stimulates uterine contraction. Rapid

intravenous injection of oxytocin can cause tachycardia, chest tightness, and hypotension; so it is usually diluted 30 to 40 units into 1 L crystalloid and administered via drip. Anecdotally speaking, we have yet to see chest tightness that does not resolve after decreasing the rate of oxytocin administration.

**Methylergonovine** is a synthetic ergonovine analogue that can have LSD-like actions above 2 mg. The dose for uterine atony is ten times lower at 0.2 mg per intramuscular/intramyometrial injection. It can be redosed at most every 2 hours to a maximum of 5 doses. Methylergonovine can cause hypertension through vascular smooth muscle constriction and is therefore relatively contraindicated in patients with hypertension or preeclampsia. Exercise caution while using in conjunction with CYP 3A4 inhibitors such as macrolide antibiotics, HIV protease or reverse transcriptase inhibitors, or azole antifungals, as they may prolong or enhance the effect on vascular smooth muscle. Of note, though off label, in a pinch some clinicians will dilute methylergonovine to 20 μg/mL for patients with a relative contraindication to the drug and given it intravascularly 1 mL at a time with a blood pressure reading after each dose. Anecdotally speaking, this technique appears to work without uncontrolled increases in blood pressure.

**Carboprost** is a synthetic Prostaglandin$_2\alpha$ analogue that is administered 0.25 mg per intramuscular/intramyometrial injection. Carboprost should be avoided in patients with asthma given case reports of bronchospasm after administration.

**Misoprostol** is a synthetic prostaglandin $E_1$ analogue that can be used for induction of abortion, treatment of ectopic pregnancy. For treatment of uterine atony, misoprostol is administered as a single dose of 400 to 1,000 μg sublingually or per rectum. Earlier in our personal practice, we gave this drug by placing the tablets sublingually and noticed that 30 minutes later most of the drug had not been absorbed. We now routinely crush the tablets before administering them sublingually and have yet to see any side effects other than diarrhea. Of note, patients don't seem to complain about the taste.

When pharmacologic therapy for uterine atony is unsuccessful, more invasive options are available. **Uterine artery** or **internal iliac artery (formerly known as the hypogastric artery) embolization** is highly effective at controlling bleeding from uterine sources. The uterine artery provides 90% of the blood flow to the uterus. If a patient is stable enough to undergo an angiographic procedure and radiologic support is available embolization may be considered as an alternative to exploratory laparotomy. During an exploratory laparotomy, surgical ligation of these arteries can also be performed to achieve the same effect as embolization.

**Uterine compression sutures** are another option for controlling PPH due to atony. There are several techniques, including the B-Lynch, Hayman, and Pereira sutures, but each has the purpose of mechanically compressing the uterus.

More recently, **intrauterine balloon tamponade** has been used as a minimally invasive treatment option that can preserve fertility. Intrauterine balloon tamponade exerts inward to outward pressure against the uterine wall. Balloon tamponade can be performed with a number of devices, but only the **Bakri balloon** and the **BT-cath balloon** are FDA approved for this application.

If ligation, embolization, compression suture, or balloon tamponade are unsuccessful, then **hysterectomy** is required. Aortic cross-clamping may be necessary if bleeding cannot be controlled initially.

In summary, treatment of uterine atony should commence with bimanual massage and oxytocin followed by **methylergonovine**, **carboprost**, or **misoprostol**. If the patient is unstable exploratory laparotomy with likely hysterectomy must be performed. If the patient is stable with a slow bleed and previous interventions were ineffective uterine artery embolization or balloon tamponade can be attempted.

## Lacerations

Another primary source of PPH is obstetric **laceration**. Laceration should be suspected whenever the uterus is firm (not atonic) and there is still bleeding.

Vaginal bleeding can arise from laceration of the vaginal artery during pushing. Risk factors include nulliparity, advanced maternal age, and fetal macrosomia. The vaginal artery can originate from either the internal iliac or uterine artery. If, during an operation, there are signs of bleeding out of proportion to what is seen on the surgical field, the anesthetist should check under the drapes. We have done this on numerous occasions on the labor floor (and in the operating room) and have found insidious bleeding on a number of occasions.

**Vulvar hematoma** can arise from laceration of branches of the pudendal artery. Vulvar hematoma is usually associated with severe pain. If the hematoma is small, it may be treated with ice packs and analgesics. If the hematoma is large, a second IV should be placed, and the patient should be brought to the operating room for surgical intervention.

**Retroperitoneal bleeding** is often missed and as such has led to some of the worst outcomes we are aware of—and this unfortunately includes a patient death. Retroperitoneal bleeding results from laceration of a branch of the internal iliac artery. Bruising of the flanks (Grey Turner's sign) is pathognomonic, and hematuria can also result from the bleed. **Retroperitoneal hematoma should be considered if the patient is showing signs of hypovolemia, but there is no bleeding on the field or under the drapes. If suspected, it is my personal practice (Dr. Togioka) to recommend to the obstetricians that we page general surgery, gynecology-oncology, or trauma surgery to assist in surgical exploration.**

## Other Causes of Postpartum Hemorrhage

Another common cause of PPH is a **retained placenta**, which is a placenta still in the uterus 30 minutes after delivery. A retained placenta prevents the uterus from contracting properly allowing blood vessels inside the uterus to continue to bleed. It is now controversial whether the umbilical cord should be pulled in an attempt to help the placenta separate. If a retained placenta is causing significant bleeding the obstetric provider will enter the uterus with their hand and attempt to remove it. Uterine relaxation with tocolytic medication aids the obstetrician in removing the placenta. Inhalational anesthetic agents, low-dose nitroglycerine, terbutaline sulfate, and magnesium may be used for this purpose.

Abnormal placentation occurs when the placenta attaches abnormally to the myometrium. The three categories of abnormal placentation are **placenta accreta** (attachment to the myometrium), placenta **increta** (invading into the myometrium), and placenta **percreta** (invading through whole thickness of myometrium). Abnormal placentation is associated with heavy blood loss of at least 2.5 to 5 L. Therefore, delivery is usually by way of cesarean section with general anesthesia, an arterial line, and large-bore intravenous access or a central line.

**Disseminated intravascular coagulation (DIC)** is a condition characterized by massive activation of the clotting cascade, widespread thrombosis, and consumption of clotting factors/platelets leading to massive bleeding and multiorgan failure. DIC had a prevalence of 12.5 per 10,000 deliveries and accounted for one-quarter of maternal deaths in the United States from 1998 to 2009. Ironically, peripartum hemorrhage itself is a common cause of DIC. Other causes include amniotic fluid embolism, sepsis, and intrauterine fetal demise. One should make sure to inspect IV sites for bleeding to trigger suspicion for DIC.

## General Response to Bleeding

The initial management of a patient with unexpected PPH can be challenging as they will most likely present with limited IV access and an unprotected airway. **The first line of action should be to call for help**. Next, call for blood products and establish additional intravenous access. **Consideration should be given to placing an arterial line** to help guide transfusion therapy. Arterial line placement is in the basic skill set for anesthesiologists—you don't ever want to be in the position of trying to explain why you didn't do something that you have done hundreds of times or more for other types of patients. **Also, don't forget about the airway!** Intubating the patient may be necessary to protect the airway as significant bleeding can lead to airway edema or an altered mental status. Don't wait too long to secure either the arterial line or the airway.

Some providers suggest activating the massive transfusion protocol if estimated

blood loss is greater than 1,500 mL. Massive transfusion protocols generally suggest giving a ratio of blood product that mimics transfusing whole blood. Packed red blood cells (PRBC) and fresh frozen plasma (FFP) are usually given in a 1:1 ratio. For every 6 units of PRBC and 6 units of FFP that are given, 1 unit of platelets is given. These protocols are based mainly upon retrospective studies involving trauma victims in the military. There is no study in the obstetric setting showing improved maternal outcomes when transfusion is performed with a high FFP:PRBC ratio. Furthermore, there are risks with giving more FFP: increased incidence of infection, higher incidence of organ failure, and risk for acute respiratory distress. To this extent, we don't hold steadfast to the 1:1 ratio. Usually, we start by transfusing PRBC only and if bleeding continues, we then start to add in FFP. By the end of the case, we are usually happy if my ratio of FFP-to-PRBC is between 1:2 and 1:1 (i.e., we don't think it is advantageous to give FFP faster than PRBCs to play catch up).

A hemoglobin concentration, calcium level, and coagulation panel (aPTT, PT, fibrinogen, platelet count) should be sent regularly to monitor the progress of transfusion. Cryoprecipitate is usually given in response to a low fibrinogen level. Another important aspect of resuscitation is the maintenance of a normal blood pH, as patients with a pH <7.2 have impaired clotting. In the severely acidotic patient, consider giving bicarbonate or increasing minute ventilation to induce a respiratory alkalosis.

If bleeding continues, you can consider tranexamic acid, which has been proven as an effective treatment for menorrhagia. While tranexamic acid has limited evidence of efficacy in the obstetric population, there is ample evidence of efficacy in the trauma setting and in elective orthopedic, vascular, and liver surgery. We have used it with some success on a few occasions in a dose of 1 g dripped in over 5 to 10 minutes. Of note, it can be repeated 30 to 60 minutes later if needed.

If massive blood loss is expected, consider cell salvage. **Cell salvage** is a method of suctioning up lost blood and processing it in order to transfuse it back into the patient. Cell salvage has been delayed in its introduction to obstetrics due to the risk for amniotic fluid embolism (AFE) and isoimmunization. The pathophysiology of **AFE**, which is characterized by hypoxia, cardiovascular collapse, and coagulopathy, is not completely understood, but is thought to be an anaphylactoid reaction rather than an embolic phenomenon. While the medical literature has not shown a clear link between cell salvage and AFE, the safety of cell salvage has also not been proven. That said, we have used cell salvage on occasion for patients with an accreta and did not encounter any adverse reactions.

## TAKE HOME POINTS

- Postpartum hemorrhage makes up a significant portion of maternal mortality, and diagnosis and treatment should be performed swiftly. It is not a historical issue, the incidence is actually increasing.
- Uterine atony is the most common cause, with other causes including lacerations, retained products of conception, and coagulopathy.
- There are several treatments for atony available, and the obstetric anesthesia team should be well-versed in these options given the frequency of this condition. **Abundant intravenous access is essential, as is airway protection in the case of massive transfusion.** Have a very low threshold for an arterial line.
- Cell salvage can be considered in cases where massive hemorrhage is expected, but its safety is unproven.

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# From Glad to Sad (Part 1): Pain Control After Cesarean Section

Michael Carrigan, MD and Brandon Michael Togioka, MD

The peripartum period is filled with a whirlwind of changes for new mothers; adding a surgical procedure to the mix can magnify their struggle to care for their baby and themselves. Optimizing pain control for cesarean section patients is crucial to their immediate and even long-term health since we now know that poor acute pain control has been linked to the development of chronic pain.

Post-cesarean section patients experience mainly nociceptive pain (i.e., pain caused by stimulation of peripheral nerve receptors that only fire if there is a stimulus that the body perceives as potentially harmful). The nociceptive pain that pregnant women experience can be further divided into three categories: **visceral** (diffuse, difficult to locate pain from the uterus), **deep somatic** (dull, achy musculoskeletal pain), and **superficial somatic** (sharp, easily located pain from skin injury). Post-cesarean section pain effects extend beyond that of simple discomfort and may include shallow breathing with associated atelectasis, decreased mobility with a higher risk for DVT/PE, increased difficulty breastfeeding, and potentially higher rates of postpartum depression.

Recognizing the importance of pain management, the Joint Commission Mandate of January, 2001 incorporated pain as the fifth vital sign and emphasized collaborative, interdisciplinary, and multimodal approaches as the new paradigm. In this spirit, utilizing opioid-sparing medications such as nonsteroidal anti-inflammatory drugs (NSAIDs) and acetaminophen is now standard practice. In the postpartum period, this multimodal approach has been shown to minimize side effects for both mother and baby.

## IV Opioids

Opioids have long been first-line therapy for postoperative pain control. Preferred administration is in the form of patient-controlled analgesia (PCA), as it is both empowering to and satisfying for patients in addition to liberating the nursing staff from having to administer the medication themselves. The PCA method of administration tends to provide a more consistent plasma opioid concentration than provider administered opioids. While the pain control from opioids tends to be good, opioids are associated with multiple side effects (described below). In general, it is a good rule of thumb to attempt transition to oral opioids as soon as possible to facilitate intravenous line removal and discharge home. In our practice, most patients receive intrathecal or epidural morphine and so are able to be transitioned to oral opioids in the PACU (Table

253.1).

## Nonsteroidal Anti-Inflammatory Drugs

While generally ineffective as sole therapy, NSAIDs have a demonstrable opioid-sparing effect and thus should be considered in the postoperative period. Through cyclooxygenase (COX) inhibition NSAIDs are thought to relieve pain by stopping the production of prostaglandins (molecules that sensitize nerves to pain). Two major forms of COX have been described. COX-1 appears to be important for kidney and platelet function as well as protection against stomach ulcers. COX-2 appears to be more involved in inflammation and pain. For this reason, selective COX-2 inhibitors (e.g., celecoxib and rofecoxib) were created. COX-2 inhibitors received much bad press because they were associated with an increase in heart attacks and strokes; however, this increase in vascular complications is similar to that seen in nonspecific NSAIDs. Regardless, the bad press led to rofecoxib being removed from the market. Celecoxib is still available and useful when a mother can take PO medications.

**Table 253.1 ■ Common Opioid Side Effects and Typical Treatments Attempted in the Postpartum Period**

| Side Effect | Potential Treatments |
|---|---|
| Constipation | Docusate and sennosides |
| Nausea or vomiting | Ondansetron, metoclopramide, and promethazine, P6 acupuncture pressure or needles, as a last resort subhypnotic doses of propofol can break the cycle |
| Itching | Nalbuphine 2.5 mg IV |
| Respiratory depression | Stop the narcotic and intermittently dose 40 mcg IV naloxone until the respiratory rate improves |
| Sedation | Attempt to decrease the dosage by adding adjuvant nonopioid pain medications or regional pain control (e.g., TAP block, epidural); as a last resort caffeine can be helpful |

Commonly used nonspecific NSAIDs in the postpartum period include ketorolac, ibuprofen, and naproxen. Ketorolac is especially helpful when postoperative bleeding is not a concern as 30 mg of ketorolac can provide analgesia similar to 10 mg of IV

morphine. In our practice, most patients that have normal bleeding (<1,000 mL EBL) receive 30 mg of ketorolac before leaving the operating room. In addition, most patients are given a standing order for 600 mg of ibuprofen every 6 hours until discharge. NSAIDs are excreted in breast milk at low concentrations and are generally thought to be safe, with the possible exception of mother's breastfeeding neonates that are dependent upon fetal circulation.

## Acetaminophen

Acetaminophen is a commonly overlooked medication in the postoperative period. The mechanism of action for acetaminophen is still incompletely understood, but it appears it may be mediated by COX-2 inhibition. Similar to the COX-2 inhibitors it is less likely to be associated with ulcer formation or clotting defects. Acetaminophen, like NSAIDs, has an opioid-sparing effect. It is cheap and generally safe in the acute setting in patients without liver disease. Rectal administration is common and especially suited for women with a lower-extremity block from neuraxial anesthesia. Over the past decade the use of propacetamol (IV acetaminophen) has greatly increased; however, there is a lack of evidence that it is any better than rectal or oral acetaminophen and it is much more expensive. In general, propacetamol should be reserved for patients that will not be able to tolerate oral medications for an extended period of time and cannot get rectal acetaminophen. It is our personal preference, to give all patients one dose of 650 mg rectal acetaminophen in the operating room and then provide a PRN order for 650 mg oral acetaminophen every 6 hours for the remainder of their hospitalization.

## Postoperative Epidural: Patient-Controlled Epidural Analgesia

As many patients that have a cesarean section will have an epidural catheter in place, another option for post-cesarean section pain control is epidural analgesia. While epidurals have been shown to repeatedly offer excellent pain control, many centers are unable to offer post-cesarean section epidural analgesia because it requires that an anesthesiologist be available to trouble shoot the catheters 24 hours a day. Most centers that offer epidural pain control now utilize patient-controlled epidural analgesia (PCEA) as it has been shown to have the following advantages over a continuous infusion of medication: it empowers the patient, it receives high patient satisfaction ratings, it reduces the total dosage of medication leading to less side effects, it allows for less nursing and physician interruptions to breast feeding, and it reduces nurse burden. Commonly, a solution of local anesthetic and opioid will be infused through the epidural catheter. A low concentration of local anesthetic combined with a lipophilic opioid (e.g., fentanyl, sufentanil) is likely the optimal regimen. This will allow for more

maternal mobility by limiting the concentration of local anesthetic administered while limiting the systemic effect of the opioid on either mother or baby. Because of the risk for infection, the epidural should be removed as soon as the new mother is tolerating and getting benefit from oral pain medications.

Ideally, all epidurals for postoperative analgesia should be placed in the thoracic region to avoid impairing ambulation. As labor epidurals are placed in the lumbar region, we prefer not to use them in the postoperative period unless patients have a very strong indication for postoperative PCEA (e.g., patients on methadone or buprenorphine). We have found that multiple days of oral opioid drug titration, after the PCEA is turned off, is usually required to get chronic pain patients on a tolerable regimen for discharge. To this extent, providing a PCEA to these patients for more than few days can prolong their length of hospitalization.

## Preservative-Free Morphine (AstraMorph, Duramorph)

Preservative-free morphine has become very popular in the postpartum period. It is administered into either the epidural or intrathecal (i.e., spinal) spaces. It is much less lipophilic than other opioids and thus stays in the central nervous system producing prolonged pain control. The optimal epidural dosage after cesarean section appears to be around 2 to 3 mg, with a peak effect around 60 to 90 minutes after administration. Epidurally administered morphine can provide pain control for up to 24 hours. A spinal dose of 100 to 150 mcg morphine seems to be similarly optimal. The peak effect of spinal morphine is faster (~45 minutes) and the duration of action is also 24 hours. When using preservative-free morphine, other opioids should be used judiciously for 12 hours and vigilance maintained for delayed respiratory depression for 24 hours. Neuraxial (i.e., epidural and spinal) morphine results in two peaks in plasma concentration. The first peak occurs 45 to 90 minutes after administration and the second peak occurs 6 to 18 hours after administration.

At our institution, neuraxial morphine is given to almost every patient that has a cesarean section under regional anesthesia. We have found that it helps transition patients to oral opioids faster while likely minimizing fetal exposure to opioids through breast milk. Unfortunately, neuraxial morphine is associated with postoperative nausea and vomiting (PONV) and pruritus. PONV can be treated with ondansetron and dexamethasone; metoclopramide has little evidence of effectiveness in this population. Neuraxial opioid induced pruritus can be quite difficult to treat. We have found that minimizing the dose of neuraxial morphine (higher doses than those described above are associated with more side effects without any improvement in analgesia) and providing PRN doses of nalbuphine (2.5 mg) for itching provides most patients with a satisfactory postoperative course.

## Local Anesthetic Infiltration and TAP Blocks

Local anesthetic infiltration of the surgical incision can greatly decrease postoperative somatic pain. Whether it be via surgeon wound infiltration or a targeted abdominal wall nerve block (e.g., transversus abdominis plane [TAP] block), regional anesthesia can be opioid-sparing. Interestingly, there does not appear to be a significant benefit from regional anesthesia in patients that receive intrathecal morphine. In our practice, we offer rescue TAP blocks (a block in the PACU) to all patients that have general anesthesia for cesarean sections. We try to broadly consent patients for the TAP block at the first hint of a possible general anesthetic. Patients are not considered consentable after general anesthesia. TAP blocks will only cover incisional pain; they do not touch visceral pain. **Thus, when performed after surgery TAP blocks can be quite gratifying and impart partial immediate analgesia.** While the TAP block can be safely performed under general anesthesia, we prefer the rescue block as patients have a hard time understanding that a block was performed when they wake up with visceral pain.

## Analgesia and Breastfeeding

All medications administered to patients need to be filtered with additional scrutiny if the mother plans to breastfeed. Breastfeeding is associated with many neonatal benefits including passive immunity, less autoimmune disease, a reduction in the risk for Sudden Infant Death Syndrome (SIDS), and potentially improved developmental outcomes. In addition, it can help the mother by providing for more oxytocin production and potentially a decreased risk for postpartum uterine atony. The American Academy of Pediatrics (AAP) recommends breastfeeding for the first 6 months of a child's life. Good postoperative pain control can facilitate early success with breastfeeding. Methods to limit neonatal risk from pain medications include choosing drugs with a long history of safe use, using the lowest effective dose, and dosing immediately after breastfeeding. The following is a brief list of common drugs and their safety category. For a comprehensive database of information on drugs and their impact on breastfeeding please visit http://toxnet.nlm.nih.gov/newtoxnet/lactmed.htm (Table 253.2).

**Table 253.2 ■ The Safety of Commonly Used Pain Medicines in Breastfeeding Women**

| Likely Safe | May Use With Monitoring | Use Is Discouraged |
|---|---|---|

| | | |
|---|---|---|
| Acetaminophen | NSAIDs (have been associated with neonatal GI bleeding and kidney damage) | Aspirin (can cause a metabolic acidosis in the neonate) |
| Caffeine | Ketorolac (black box warning not to use in nursing mothers yet the AAP okays its use) | Meperidine (can accumulate in the baby causing lethargy) |
| Fioricet (butalbital, acetaminophen, caffeine) | Oxycodone (a significant percentage is secreted into breast milk so limit the dosage) | |
| Celecoxib | Codeine (some women are ultrarapid metabolizers which can lead to very high levels in infants) | |
| Hydromorphone | | |
| Morphine | | |
| Fentanyl | | |
| Methadone (<20 mg/day likely safe) | | |

## TAKE HOME POINTS

- Optimizing pain control for cesarean section patients is crucial to their immediate and long-term health.
- IV PCA and PCEA are the preferred methods of delivery for IV and epidural medications.
- A multimodal approach to postoperative pain control is optimal and the use of NSAIDs and acetaminophen are encouraged to limit both the dosage and side effects from opioids.
- A ceiling effect exists for preservative-free morphine (i.e., ~3 mg epidural, 150 mcg intrathecal) above which pain control is not improved, but patients have more side

effects. Patients that receive neuraxial morphine need to be monitored for delayed respiratory depression.

- Many medications can be safely administered to breastfeeding women after a cesarean section.

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# From Glad to Sad (Part 2): Postpartum Neuropathy of the Lower Extremity

Seth Palesch, MD and Brandon Togioka, MD

Although infrequent, nerve injuries can occur in otherwise healthy women on labor and delivery. The vast majority of these injuries are intrinsic to the childbirth process, which means that they are caused by the act of laboring and delivering a baby. The overall incidence of obstetric nerve injuries is difficult to determine, but for purposes of informed consent it can be estimated to occur in 0.006% to 0.92% of patients that present in labor.

Peripheral nerve palsies make up the majority of obstetric-related neuropathies. These injuries usually occur in the legs and are due to either compression or stretching of the lumbosacral plexus or peripheral nerves. While the injury is caused by the birthing process, laboring women with neuraxial anesthesia (spinals or epidurals) lose a major safety mechanism that the body uses to protect itself—pain. Under normal circumstances, patients will use their muscles to counteract any extreme compression or stretching of a nerve that can cause injury. A woman with the distracting pain of labor combined with the analgesic effect of an epidural will not protect herself in the same way. **Thus, neuraxial anesthesia can be considered a risk factor for postpartum neuropathies. Other risk factors associated with postpartum peripheral neuropathy include nulliparity (a woman having her first baby), a long second stage (pushing stage) of labor, prolonged lithotomy positioning (especially with extreme flexion of the hips), cephalopelvic disproportion (the baby's head is too big to fit through the mother's pelvis), nonvertex fetal presentation, instrument-assisted delivery, and preexisting neurologic deficits.** Empower patients with preexisting injuries to find a pushing position that is most comfortable to them (there are multiple positions that work for the second stage of labor) as pain can be an indicator of nerve compromise (Table 254.1).

**Table 254.1 ■ Common Peripheral Nerve Palsies Seen in Obstetrics**

| Nerve | Nerve Roots | Sensory Deficit | Motor Deficit |
|---|---|---|---|
| Lumbosacral plexus | L1–S4 | Usually the distribution of the peroneal nerve | Usually the same deficit as the peroneal nerve |

| | | | |
|---|---|---|---|
| Obturator nerve | L2–L4 (anterior division) | Medial thigh and knee | Thigh adduction |
| Femoral and saphenous nerve | L2–L4 (posterior division) | Anterior thigh, medial lower leg, and medial arch of the foot | Hip flexion, knee extension, and patellar reflex |
| Lateral femoral cutaneous nerve | L2–L3 | Lateral thigh, "meralgia paresthetica" | None |
| Sciatic nerve | L4–S3 | Buttock, posterior thigh, entire lower leg except the medial side, and most of the sole of the foot | Knee flexion |
| Posterior tibial nerve | L4–S3 | Sole of foot | Foot plantar flexion and inversion |
| Common peroneal nerve | L4–S2 | Lateral lower leg, dorsum of foot | Foot dorsiflexion and eversion (foot drop) |

Adapted from Wong CA. Nerve injuries after neuraxial anaesthesia and their medicolegal implications. Best Prac Res Clin Obstet Gynaecol. 2010;24(3):367–381. Copyright ©2009 Elsevier. With permission.

Of the specific peripheral nerve palsies, **injury to the lateral femoral cutaneous nerve (LFCN) is most common during pregnancy**. Injury to this nerve has a special name: meralgia paresthetica. The LFCN is commonly injured due to compression by the inguinal ligament when a woman is pushing in a thigh-flexed position. Injury to the LFCN results in numbness, tingling, or a burning sensation in the lateral thigh. LFCN injury does not cause any weakness. General risk factors associated with this injury include any increased intra-abdominal pressure (e.g., pregnancy, obesity), diabetes mellitus, trauma to the inguinal canal, iatrogenic applied belt pressure, and extreme lithotomy positioning. It is possible for the LFCN to be injured during cesarean delivery via stretching or pressure from a low retractor. However, since the nerve originates from the L2–L3 nerve roots and extends lateral to the transverse process, injury solely due to regional anesthesia has yet to be reported in the literature.

The femoral nerve is the second most commonly injured nerve during the peripartum

period. Injury to the femoral nerve may result in anterior thigh and medial lower leg sensory deficits with weakness in hip flexion and knee extension. Like the lateral femoral cutaneous nerve, it is usually injured by compression at the inguinal ligament during pushing. A relatively poor blood supply to the proximal portion of the nerve seems to predispose it to injury.

Since the obturator nerve descends through the true pelvis, it is usually injured by direct compression during childbirth either by the fetal head or by forceps. Obturator nerve injury can result after pudendal nerve block if a hematoma develops. Injury to the obturator nerve will result in a medial thigh sensory defect and problems with thigh adduction.

The sciatic nerve splits into the common peroneal and posterior tibial branches. Common peroneal nerve injuries result in a sensory defect to the lateral lower leg and motor deficits in foot dorsiflexion and foot eversion. Injury to the posterior tibial nerve causes a sensory deficit to the sole of the foot with loss of foot inversion and plantar flexion. Since both nerves arise from the sciatic, the risk factors for injury are similar: relaxation of the sacroiliac joint during pregnancy and prolonged lithotomy positioning causing sciatic nerve stretching. Classically, the common peroneal nerve is injured through external compression by inappropriate positioning in stirrups.

Among the most feared complication from neuraxial anesthesia (spinals and epidurals) are epidural hematomas and abscesses. The estimated incidence of each is: between 1 in 500,000 to 700,000 procedures for epidural hematoma and between 1 in 200,000 to 500,000 procedures for epidural abscess. As with most complications related to anesthesia, safe practices and a thorough patient history that includes checking for bleeding disorders and signs of skin infection (especially Staphylococcus aureus) can help prevent disastrous outcomes. Epidural hematomas will often present within 24 hours of epidural placement or removal with acute onset back and radicular leg pain, lower-extremity weakness that is getting worse, and potentially bowel and bladder incontinence. Epidural abscesses will often present within 4 to 10 days of epidural or spinal insertion with continuous severe back pain, fever, a leukocytosis, and potentially a headache or neck stiffness. **Because abscesses often present after the patient has been discharged, it is important to inform the patient of this potential complication and tell them to inform any future medical providers of their recent spinal procedure. In our experience, the worst lawsuits and outcomes have been associated with epidural abscesses being missed in the emergency department despite multiple patient visits, because the emergency department did not consider an epidural abscess in their differential diagnosis. Anesthesia providers can be held liable for not warning patients of this potential complication.** Epidural hematomas and abscesses are both considered true neurologic emergencies and require stat MRI.

For both, earlier neurosurgical decompression is related to better long-term outcomes.

Cauda equina syndrome (CES) typically occurs in obstetric anesthesia as a result of either direct trauma or local anesthetic toxicity to the nerve roots below the conus medullaris (typically around L1–L2 in an adult). These nerve roots are especially vulnerable to toxicity because they are poorly myelinated. CES can result in bowel and bladder dysfunction, severe back pain, sexual dysfunction, variable lower-extremity paresthesias/paresis, and saddle anesthesia (sensory loss to the perineum). Spinal microcatheters (very small catheters left in the intrathecal space) have been linked to CES. They seemed to cause CES by allowing for pooling of high concentrations of local anesthetics around the poorly myelinated nerve roots of the cauda equina. Of all the local anesthetics, lidocaine was particularly implicated and as such many providers have stopped using high concentration lidocaine for spinal anesthesia. Treatment for suspected CES is supportive with physical therapy, occupational therapy, and pain treatment.

Transient neurologic syndrome (TNS) is a diagnosis that consists of transient, self-limited achy or crampy pain in the lower back/buttock or radicular pain in the lower extremities after an uncomplicated epidural or spinal. TNS should not cause any motor weakness and no one knows what causes it. It typically starts 2 to 24 hours after an anesthetic and can last several days. Treatment consists of bed rest, reassurance, and typically nonsteroidal anti-inflammatory drugs (NSAIDs). Like CES, intrathecal lidocaine has been linked to TNS. Other risk factors include lithotomy positioning and outpatient surgery.

When presented with a patient with a potential postpartum neuropathy, it is important to first rule out any life-threatening or paralysis-threatening injuries (e.g., an epidural hematoma or abscess). We usually do this by asking if the patient is having a progression in weakness or uncontrolled pain. Any motor weakness that is progressing after the epidural is turned off, especially if it is associated with uncontrolled back pain, should trigger a stat MRI and emergent neurosurgical consult. Any improvement in symptoms is a reassuring sign and decreases the pretest probability that an MRI would find an epidural hematoma or abscess. **It is also helpful to remember that all published obstetric epidural hematomas and abscesses have presented with bilateral symptoms, so one leg weakness is very unlikely to require an MRI.** We will then conduct a detailed and documented neurologic examination looking for motor or sensory deficits in the affected extremities. An evaluation of the paraspinal muscles can also be helpful, as intact sensation and strength in the lower back likely means that the injury involves a peripheral nerve only. In most patients, the presence of an epidural hematoma or abscess can be ruled out clinically, allowing you to focus on the peripheral nerve involved.

Peripheral nerve palsies discovered after delivery are usually painless, stable, and show signs of improvement. The questions for anesthesia providers surrounding peripheral nerve injuries are usually:

) Did anesthesia cause this injury?
) What should we do about it?
) What is the patient's prognosis?

The answer to the first question is usually unclear, but if the patient got neuraxial anesthesia I usually say that we contributed to it (as discussed in the second paragraph in this chapter), but did not directly cause it. The answer to the second question is usually watchful waiting and reassurance, especially if the symptoms seem to be improving with time. Electromyography (EMG) is typically not indicated unless one wants to show signs of preexisting injury. Signs of nerve damage can take 2 to 3 weeks to show up on EMG. In addition, steroids and medications to artificially raise blood pressure are typically not helpful. With regards to prognosis, most sensory deficits will make a near complete recovery. New motor weakness can require physical therapy to help prevent contractures and muscle atrophy as it can take months for recovery to occur.

## TAKE HOME POINTS

- While peripartum neuropathies are usually a byproduct of the birthing process, neuraxial anesthesia predisposes women to have these injuries because they lose a major safety mechanism that the body uses to protect itself—pain. This is a risk of analgesia for labor and delivery and should be discussed with the patient.
- The most common peripartum peripheral nerve palsy is damage to the lateral femoral cutaneous nerve. Injury to his nerve has a special name, meralgia paresthetica, and will cause numbness, tingling, or pain in the lateral thigh. It is not associated with any motor deficit.
- Other peripartum peripheral neuropathies involve the nerves of the lumbosacral plexus and the nerve injured can be identified based on presenting symptoms. Most peripheral nerve injuries will resolve on their own within months.
- Epidural hematomas and abscesses are thankfully very rare, but true emergencies. Suspicion for either requires stat MRI and neurosurgical consult.
- Cauda equina syndrome from direct trauma or local anesthetic toxicity results in bowel and bladder dysfunction, severe back pain, sexual dysfunction, and variable lower-extremity paresthesias and paresis.
- Transient neurologic syndrome is a constant achy or crampy pain in the lower back/buttock that results after an uncomplicated spinal, or rarely epidural. There is

no associated motor weakness and it resolves without treatment.

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# Obstetric Anesthesia/Analgesia Can Work in a Small Hospital: The Key Principles Are Commitment, Flexibility, and Planning

James S. Hicks, MD MMM and Jordan Johnson, MD

The ability to offer obstetric (OB) conduction anesthesia to laboring patients in a small hospital where 24-hour in-house anesthesia coverage is not available or feasible is challenging but affords the anesthesia department an opportunity to provide excellent service both to patients and obstetric colleagues. To be successful, interposing obstetric conduction anesthesia services within a surgical schedule and managing the same service after usual operating room hours require careful planning, interdisciplinary cooperation, and ongoing continuous quality improvement.

Among the challenges that must be addressed to provide satisfactory small hospital OB services are the following:

- Recognize and minimize the potential delay in the elective surgical schedule required to perform labor epidurals
- Recognize and minimize the delay in responding to requests for epidural anesthesia due to the unavailability or on-call status of the anesthesia provider
- Manage the potential inability to provide timely emergency cesarean section anesthesia
- Recognize the need for obstetric nurses to assist with management of epidural infusions and provide them with appropriate education and experience
- Meet regulatory requirements

Surmounting these obstacles requires a commitment on the part of the anesthesiology service to the principle that obstetric anesthesia is no less of a priority than surgical anesthesia, and subsequently gaining agreement from all involved stakeholders. This does not imply that obstetric anesthesia will take priority on the surgical schedule, but simply that the efforts to meet the needs of obstetric patients are genuine, compassionate, and equivalent to our efforts to provide excellent surgical anesthesia.

Successful rural OB service is achievable. The American Society of

Anesthesiologists' (ASA) Consultation Program has provided hospitals with the expertise of board-certified anesthesiologists who are specially trained in assessing anesthesia practices and in providing recommendations for improvement. The program also provides the ASA with a multiple-exposure snapshot of many anesthesia practices, many of which involve rural anesthesia coverage. The following recommendations are the result of experiences drawn from observations gained from this program throughout the United States:

1) Convene a "council of stakeholders" composed of anesthesia providers, obstetricians (and, if applicable, family practitioner and certified nurse-midwife obstetric providers), surgeons, emergency physicians, obstetric nurses, pharmacists, and hospital administrators. Obtain consensus from this group that labor epidural analgesia for all patients desiring such is a worthwhile and desirable goal. To gain this consensus, council members must first acknowledge that the needs of obstetric patients may require customization of policies that would, if otherwise applied, preclude the ability to have full-time labor analgesia coverage. For example, pharmacists need to acknowledge the need to maintain adequate supplies of premixed epidural solutions, even if this results in occasional outdates of solutions. Obstetric nurses must be willing to titrate epidural anesthesia infusions (given clear parameters and orders) in the face of a national organization's recommendations to the contrary. Surgeons must acknowledge the occasional delay between cases for the anesthesia provider to place an epidural catheter. None of these roadblocks has proven to be an obstruction to the small hospital and anesthesia service that are determined to offer comprehensive OB anesthesia coverage, however.

2) Meet as an anesthesia service and adopt standardized processes for epidural and cesarean section techniques and procedures so anesthesia providers can easily manage blocks, surgical anesthetics, and postoperative patients of colleagues. Ideally, this should include standardization of:

- Labor epidural agent mixture
- Order sheet, anesthesia record (if different from the surgical record), billing forms and practices
- Cesarean section techniques and preferences (opioid mixtures and local anesthetic mixtures for both elective cesarean section spinals and labor epidurals used for cesarean section)

Such standardization, when placed in documentation, should clearly appear as

"suggested techniques" with a disclaimer that providers must use medical judgment and be permitted to modify suggested practices when appropriate.

3) Perform a task analysis of all tasks necessary to accomplish a labor epidural (e.g., examining the chart; taking history and performing a physical examination; obtaining pump, infusion bag, gloves, epidural tray and anesthesia cart, placing, test dosing, and securing catheter and beginning infusion). Request that nursing staff complete all possible steps in the task analysis (step 3) that can be safely accomplished by them prior to your arrival. This step is vital to your ability to place an epidural quickly during a break in a busy surgical schedule.

4) Prepare an educational course for obstetric nursing staff that can be recorded for future additions to the staff. This should include those elements of anatomy (especially body habitus and airway examination), physiology, pharmacology, a demonstration of the technique of epidural, spinal, and combined spinal-epidural placement, dosage management, and management of possible complications.

5) Certify the competence of nurses who successfully complete the labor analgesic course after observing them manage a given number of epidurals. (This will give them increased assurance in managing epidural infusions in the face of contradictory information from their national organization recommendations.)

6) Discuss with surgical colleagues the intent to provide labor epidural service with minimal interruption of the surgical schedule and request their cooperation.

7) Plan in advance for labor epidurals whenever possible. This means contacting the labor floor early in the morning for patients who will likely need an epidural during the morning, as well as placing and testing a catheter before the beginning of the surgical schedule. As soon as the patient then requires pain relief, the infusion may begin without a bolus dose at the usual rate. This results in an effective dose being achieved in approximately the same time frame as would have occurred had the usual sequence of notify-attend-insert-test-bolus taken place. Request obstetric providers and obstetric nursing staff to make you aware of patients with risk factors such as morbid obesity, preeclampsia, coagulopathies, and other obstetric or medical complications that could cause a delay in epidural placement.

8) An anesthesia provider's rest is important when he or she is on call for the operating room and/or is expected to provide anesthesia the following day, as is often the case at smaller hospitals. By maintaining frequent communication with obstetric nursing staff, checking the labor floor before departing for the day or after an on-call surgical

case, and encouraging nurses to call sooner rather than later for epidural consults and placements, return trips to the hospital or loss of sleep can be minimized.

9) Obtain assurance from emergency department physicians that they will respond to the extremely rare instance of adverse reaction to an established epidural analgesic, and educate them on the possible complications. The use of a test dose coupled with an extremely low local anesthetic concentration (the authors' department uses 0.055% bupivacaine with 1 mcg of sufentanil/mL) make the possibility of such complications almost nonexistent.

10) The question is often asked, "Do I have to remain in the hospital during the entire course of a labor epidural?" According to the ASA, the answer appears in the introduction to the Guidelines for Neuraxial Anesthesia in Obstetrics: "Because the availability of anesthesia resources may vary, members are responsible for interpreting and establishing the guidelines for their own institutions and practices …." Thus, the ASA acknowledges that local convention based on capability and personnel are determining factors in obstetric anesthesia services and allows hospitals to meet their standards in ways that are best for patients.

## TAKE HOME POINTS

- The first step in providing OB services in a small or rural hospital is recognizing the challenges.
- There must be commitment from surgeons, obstetric providers, obstetric nurses, hospital administrators, and anesthesia team members to the principle that obstetric analgesia/anesthesia is no less important than surgical anesthesia.
- Standardization of anesthetic techniques for labor epidurals and cesarean sections is of paramount importance.
- Obstetric nurses must be willing to accept training in and perform certain aspects of the setup and management of labor epidurals.
- Complications due to labor epidurals can be minimized by use of standardized techniques, careful test dosing of catheters and very low-dose epidural infusions.

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# Resuscitation of the Pregnant Cardiopulmonary Arrest Patient: Not Just Standard ACLS

L. Michele Noles, MD

The current estimate of maternal cardiopulmonary arrest in pregnancy is 1:20,000. This represents an increase in recent years led in part by the increasing average maternal age and maternal comorbidities including acquired maternal heart disease.

Cardiopulmonary arrest in the pregnant patient is complicated by the physiologic changes of pregnancy and the presence of two patients, mother and fetus. The initial immediate resuscitation interventions are dictated by standard American Heart Association (AHA) basic life support/advanced cardiac life support (BLS/ACLS) algorithms with some modifications in response to maternal–fetal physiology. The overall goal of maternal cardiopulmonary resuscitation is a rapid return of spontaneous circulation (ROSC), resolution of the underlying cause of the arrest, and both maternal and fetal survival. Indeed, in the early part of the arrest, fetal survival is dependent on maternal survival. However, a gravid uterus can impair circulation and negatively impact CPR leading to diminished placental circulation and fetal distress. In the absence of a circulating rhythm and depending on gestational age, perimortem cesarean delivery (PMCD) should be performed with a goal of infant delivery no more than 5 minutes after onset of maternal cardiac arrest.

The successful resuscitation of a pregnant woman requires:

- Understanding maternal–fetal physiology and its implications on BLS/ACLS.
- The organization, speed, and effective communication of the entire OB Code Resuscitation Team.
- Identification and correction of the underlying cause of the arrest.

## Immediate Resuscitation Response

**Call for help**: Initial response to a maternal cardiopulmonary arrest includes mobilization of several distinct teams who need to come together to act as the OB Code

Resuscitation Team. Beyond the standard hospital emergency cardiopulmonary arrest response team (Code Team), **responders should include (potentially multiple representatives) from Obstetrics, Anesthesiology, Neonatology, Obstetrical Nursing, and operating room personnel including Circulator and Scrub Tech.** The complexity of the notification task coupled with the profound time pressure for both mother and fetus begs for a predetermined "OB Code Respondents" notification system that would summon all necessary parties immediately. Depending on the cause of the arrest, other teams may need to be included in a secondary notification, for example, Massive Transfusion Protocol personnel.

## Modifications From BLS/ACLS

**CPR/optimum patient position for best circulation**: Minimally interrupted, good-quality CPR remains the bedrock of resuscitation medicine. The highest-quality CPR is performed on supine patients. However, in the supine position pregnant patients above approximately 20 weeks of gestation can experience aortocaval compression caused by the gravid uterus resulting in decreased venous return and maternal cardiac output and compromised perfusion to the placenta. Maximizing left lateral tilt to relieve the aortocaval compression leads to much less effective force of chest compressions. Thus the current AHA ACLS guidelines recommend positioning the patient supine and assigning someone the role of manual left uterine displacement utilizing the one-handed ("push and up" from right side of patient) or two-handed ("pull and up" from left side of patient) technique. Alternatively, a hard wedge may be placed at approximately 30%, but without a specific wedge available, it may prove cumbersome to create and position, leading to interruptions in CPR. In the case of PMCD, chest compressions should continue without interruption throughout the delivery (Fig. 256.1).

**CPR/optimum hand position for chest compressions**: The gravid uterus causes elevation of the diaphragm and abdominal contents, so in third-trimester patients, hands should be placed 2 to 3 cm higher on the sternum than usual.

**Airway management** can be more difficult in the pregnant patient. Increased oxygen consumption by the maternal–fetal unit and the decreased functional residual capacity (FRC) due to upward elevation of the abdominal contents and diaphragm quickly lead to hypoxemia and acidosis in the pregnant cardiopulmonary arrest patient. Maternal acidosis decreases the fetal ability to excrete carbon dioxide resulting in fetal acidosis. Securing the airway can be more difficult due to an edematous, friable airway, overall weight gain, and larger breasts. An oral approach with a smaller (~6.5) endotracheal tube avoids the risk of epistaxis and will pass more easily in the edematous airway. While earlier guidelines emphasized early airway management and endotracheal intubation, the current AHA guidelines emphasize CPR first, active bag-mask

oxygenation/ventilation, and recognition of the need for advanced airway management by providers experienced in difficult airways when and if possible. If the airway is difficult, use of laryngeal mask airway (LMA) as a rescue device is encouraged in this patient population despite their increased risk of aspiration.

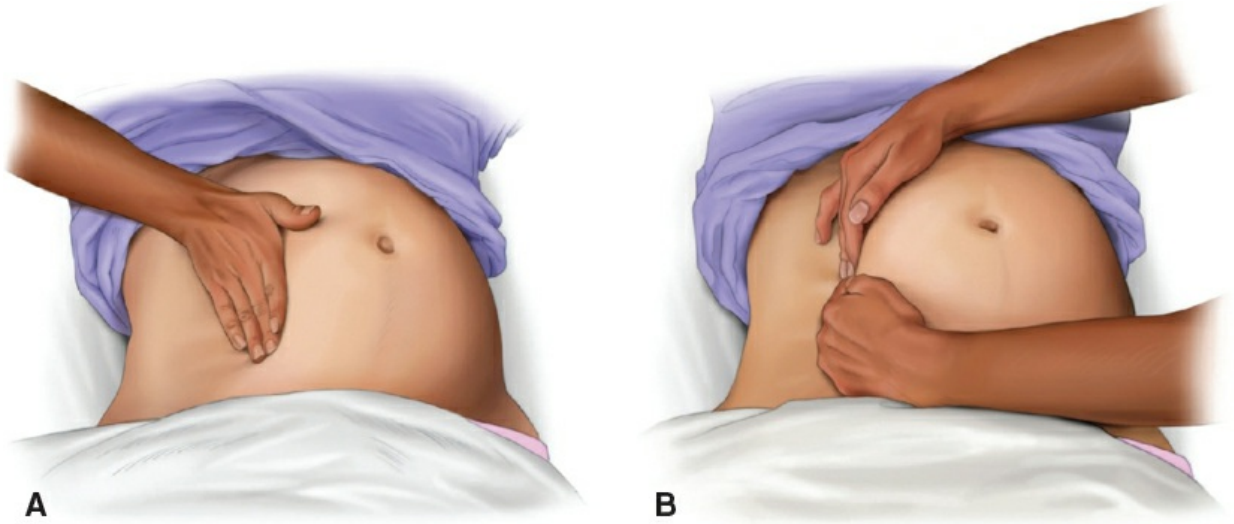


**Figure 256.1. A:** Left uterine displacement using one-handed technique. **B:** Left uterine displacement with two-handed technique. (From Jeejeebhoy FM, Morrison LJ. Maternal cardiac arrest: A practical and comprehensive review. Emerg Med Int. 2013;2013:274814. doi: 10.1155/2013/274814. Copyright © 2013 Farida M. Jeejeebhoy and Laurie J. Morrison. https://creativecommons.org/licenses/by/3.0/).

**Aspiration** is a risk but **should not discourage bag-mask ventilation** with 100% oxygen in the arrest setting: oxygenation and ventilation are far more beneficial than aspiration is risky. Cricoid pressure is no longer in the 2010 AHA ACLS guidelines and it is not specifically addressed in the cardiopulmonary arrest in pregnancy section. Active oxygenation and ventilation are encouraged with less emphasis on prevention of aspiration, especially if the aspiration prevention strategy (e.g., cricoid pressure) negatively impacts oxygenation, ventilation, or advanced airway management.

**IV access** above the diaphragm is recommended to circumvent any slowed circulation due to aortocaval compression. IV access in this population may be challenging due to tissue edema and weight gain. The humeral interosseous approach offers rapid access above the diaphragm in the case of difficult peripheral IV access. As in other cardiopulmonary arrest patients, central lines are less desirable due to the increased time required for placement and potential for interruptions in CPR.

## No Modifications

**Defibrillation** should be performed according to the standard ACLS algorithms. If possible, fetal and uterine monitors should be removed prior to defibrillation to

eliminate the minimal risk of electrical arcing, but maternal cardiac defibrillation should not be delayed for this theoretical risk. Many labor and delivery nurses are not ACLS certified. Because early defibrillation when indicated is most successful, use of an automatic external defibrillator (AED) is recommended initially if there is no expert in rhythm recognition present. Changeover to manual mode is recommended as soon as said expert arrives.

**Drugs**: Resuscitation drugs should be given according to the standard ACLS algorithms. Even with a greater volume of distribution, increased hepatic metabolism, and renal clearance in the pregnant patient, there is no evidence to support using higher than the standard recommended doses of resuscitation drugs.

**Treatment of reversible causes**: The most common causes of maternal cardiopulmonary arrest include obstetric and nonobstetric: cardiac disease (myocardial infarction, aortic dissection, cardiomyopathy), thromboembolism, pulmonary embolism, preeclampsia/eclampsia, sepsis, amniotic fluid embolism, hemorrhage, trauma, and iatrogenic causes (anesthesia-related airway management, local anesthetic systemic toxicity, magnesium sulfate toxicity). Depending on the situation, standard ACLS "H's and T's" not included in the list above should be considered. These include hypo/hyperkalemia, hypovolemia, hypothermia, hypoglycemia, hydrogen ion (acidosis), hypoxia, toxins, cardiac tamponade, tension pneumothorax, thrombosis (coronary, pulmonary), and trauma.

## Emergency Perimortem Cesarean Delivery

The decision making for PMCD includes concerns regarding:

**Maternal circulation**: The gravid uterus may cause aortocaval compression and reduce the quality of CPR beginning at approximately 20 weeks of pregnancy. In an emergency, however, the gestational age may be unknown, especially if the woman cannot communicate. Fundal height at 20 weeks is approximately at the level of the umbilicus, but may be difficult to assess in an emergency because of other injuries or the woman's body habitus. At greater than 20 weeks of pregnancy or in any obviously pregnant patient, manual left uterine displacement should always be done during CPR. In addition to clinical evaluation, adequate CPR can be measured by proxy using end-tidal carbon dioxide once there is an advanced airway in place. The adequacy of CPR will impact the decision of whether or not to proceed with PMCD.

**Gestational age**: Fetal viability is usually reported as 24 weeks of gestation. At less than 20 weeks of gestation, the gravid uterus is unlikely to cause aortocaval compression, so PMCD would probably not increase the mother's chance of survival and will guarantee fetal demise. Between 20 and 24 weeks, the decision to proceed with PMCD is centered around maternal survival. Without PMCD, the fetus survival is

dependent on maternal survival, but at this gestational age, the fetus will not survive beyond delivery. Thus, at a gestational age of 20 to 24 weeks, if maternal circulation is not adequate despite manual left uterine displacement, then uterine evacuation may represent the mother's only chance of survival. At greater than 24 weeks, uterine evacuation improves maternal circulation via CPR while also allowing for fetal survival. For every additional week of gestation, PMCD results in greater fetal survival (decreased complications of prematurity), while also enhancing the odds of improved maternal circulation by releasing the increasingly large aortocaval compression. Thus, the greater the gestational age after 30 weeks, the more benefit to both mother and baby from PMCD.

**Timing of PMCD**: In general, if the PMCD is to be undertaken, speed is of essence both to assist in maternal resuscitation and to promote good fetal outcomes. The AHA guideline advocates infant delivery by 5 minutes after maternal arrest because of better infant outcomes. This is a challenging goal. In order to be successful, team members must begin preparation for operative delivery immediately upon maternal arrest, so that once the decision is made (goal is 4 minutes into the arrest), the operation can be begun immediately leading to delivery within 5 minutes. Recent studies have shown a greater likelihood of achieving delivery within 5 minutes if the PMCD is accomplished in situ rather than attempting patient transport to the operating room.

**Maternal prognosis**: If the pregnant woman has suffered a nonsurvivable injury and the fetus is viable, perimortem cesarean section should be undertaken immediately.

**Postcardiac arrest care**: Regardless of whether the patient underwent PMCD or remains pregnant, therapeutic hypothermia should be considered as in the general population. The fetus should be continuously monitored for bradycardia.

## Team Management

There is very little doubt that the successful undertaking of so rare and complex an intervention as parturient resuscitation with the potential for PMCD will be highly dependent on excellent preparation, role recognition, communication, and teamwork organization. Simulation as a preparatory methodology has been shown to improve team management and performance in similar critical events.

There is also little doubt that these devastating clinical emergencies can be soul shaking for the provider team, especially if the mother does not survive the arrest. Do your utmost to stay calm like the well-trained provider you are but do not be surprised if you feel considerable emotional and psychological distress later. Do not ignore that distress, take whatever steps are necessary to process and resolve it.

## TAKE HOME POINTS

- Call for help/call an OB Code/call for defibrillator
- Immediate CPR at a rate of at least 100/minute, 2.5-in depth. For third-trimester patients, hands positioned 2 to 3 cm higher on sternum. Backboard as soon as available
- Patient supine with manual left lateral uterine displacement
- Airway: head tilt, jaw thrust
  - Bag mask with 100% oxygen at tidal volume 500 to 700 mL over 1 second for 2 breaths alternating with 30 chest compressions until advanced airway is secured, then 6 to 8/minute.
  - Advanced airway management by individual experienced with difficult airways if at all possible.
  - Direct laryngoscopy without interruptions of CPR if possible.
  - Have difficult airway adjuncts available if possible (LMA, GlideScope, etc.).
- Defibrillation per ACLS algorithms as soon as possible
- Begin preparations for PMCD immediately
- Obtain intravenous or interosseous access above the diaphragm as soon as possible
- ACLS drugs according to ACLS algorithm
- Determine reversible causes
- Mobilize resources for reversible causes (e.g., intralipid for local anesthetic toxicity, massive transfusion protocol for uncontrolled hemorrhage, interventional cardiologist for coronary thrombosis)
- If perimortem cesarean section indicated, proceed within 4 minutes for goal delivery time of less than 5 minutes
- Postcardiac arrest care

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# The Pregnant Anesthesia Provider (Part 1)—Managing the Occupational Exposures

Michelle Tully, MD and Emily J. Baird, MD PhD

You have recently learned that you are expecting your first child. You are not planning on announcing your news until after 12 weeks but are concerned about the impact of operating room exposures on your pregnancy. What are the unique occupational hazards and exposures for the pregnant anesthesia provider? What can you do to minimize the risks to the baby?

When an anesthesia provider becomes pregnant, she will almost certainly worry (continuously) about the effect of operating room exposures on her fetus. The four most concerning occupational hazards include blood-borne pathogens, inhalational anesthetic agents, radiation, and methyl methacrylate. Although definitive data on the impact of these exposures are limited, there are steps the pregnant anesthesia provider can take to minimize the risk of adverse fetal effects.

## Blood-Borne Pathogens

The performance of invasive procedures and the proximity to the surgical field contribute to the increased exposure of anesthesia providers to infectious diseases. The most common blood-borne pathogens are hepatitis B and C, HIV, and CMV.

The risk of hepatitis B infection ranges from 6% to 30% after percutaneous exposure. Maternal–fetal transmission of hepatitis B depends on both gestational age and viral activity, with higher rates of vertical transmission occurring later in pregnancy and/or during active viral replication. Although hepatitis B is not associated with increased rates of pregnancy complications, it can lead to the development of chronic infection in the infant. **Fortunately, postexposure hepatitis B prophylaxis can be safely administered anytime during pregnancy.** Maternally administered hepatitis B vaccine and immunoglobulin reduces the occurrence of chronic infection in the neonate to <15%.

Percutaneous exposure to hepatitis C is associated with a <7% risk of infection. Maternal–fetal transmission occurs through the placenta, increasing the risk of acute and chronic hepatitis in the neonate. Unfortunately, therapies to reduce the vertical transmission of hepatitis C are not currently available.

The risk of HIV infection after percutaneous exposure is 0.3%, with postexposure azidothymidine and lamivudine prophylaxis further reducing transmission rates. Although vertical transmission can occur at any time, the neonate is at the greatest risk

of HIV infection during delivery and with breastfeeding. In addition, the incidence of fetal HIV infection is proportional to maternal viral load. Fortunately, the rate of maternal–fetal transmission is reduced to <2% if the mother's viral load is <1,000 copies/mL at the time of delivery.

Although CMV infection is relatively benign in individuals with uncompromised immune systems, exposure during pregnancy can result in significant fetal complications including microcephaly, hepatosplenomegaly, hepatitis, chorioretinitis, thrombocytopenia, and neurodevelopmental abnormalities. Given that CMV is readily transmitted via all bodily secretions, including blood, saliva, and urine, it is not surprising that 50% to 80% of adults are seropositive for CMV. Unfortunately, CMV is also readily transmitted in utero, with maternal–fetal transmission occurring in ~30% of primary maternal CMV infections. Given the prevalence of CMV carriers and the gravity of adverse fetal outcomes, it is imperative that pregnant anesthesia providers implement universal precautions with all patients.

Fortunately, the risk of infectious disease transmission can be dramatically reduced through vigilance in the evaluation and management of patients. The anesthesia provider should carefully review patients' medical records to identify the presence and characterization (i.e., viral load) of blood-borne pathogens. Strict adherence to universal precautions, including the use of gloves, masks, and eye protection, will further minimize the risk of infectious disease transmission. Of note, "double-gloving" has been shown to be more effective at reducing percutaneous transmission rates than use of a single set of gloves. Finally, if a provider is exposed to a potential infectious pathogen, immediate medical attention should be sought and postexposure prophylactic therapies initiated.

## Inhalational Anesthetic Agents

Epidemiologic and animal studies from the 1960s suggested that inhaled anesthetic agents, including nitrous oxide and halogenated agents, increased the risk of spontaneous abortion and congenital abnormalities. Although the quality and validity of those early studies have subsequently been questioned, the effect of exposure to inhaled anesthetic agents during pregnancy has yet to be definitively characterized. A study of female physicians in England reported no association between adverse fetal outcomes and maternal occupation, hours in the operating room, or use of anesthetic gas salvaging equipment. Conversely, a recent epidemiologic study comparing pregnancy outcomes among anesthesiology subspecialties reported a higher prevalence of spontaneous abortion in pediatric anesthesiologists. The authors suggested that the greater exposure to waste anesthetic gases from inhalational inductions and uncuffed endotracheal tubes might have contributed to the increased rate of adverse pregnancy outcomes.

To mitigate any potential risk of anesthetic gas exposure, the Occupational Safety and Health Administration (OSHA) has established guidelines for safe levels of inhalation agents in the operating room. Specifically, nitrous oxide exposure should be limited to 25 ppm per anesthetic period and halogenated agents should be limited to <2 ppm per hour of anesthesia. With adequately functioning anesthesia equipment including valves, circuit tubing, gas scavenger, and ventilation systems, levels of waste anesthetic gases do not exceed these recommendations. Although evidence that inhalational inductions result in levels of waste anesthetic gases high enough to cause adverse pregnancy outcomes is lacking, the pregnant anesthesia provider may elect to avoid this technique.

## Radiation

Intraoperative radiographic imaging has become increasingly common. The effects of ionizing radiation on the fetus depend on the amount of exposure and the gestational age of the fetus. Radiation exposure during organogenesis, which occurs during gestational weeks 2 through 10, has the greatest potential for adverse fetal effects. The National Council on Radiation Protection and Measurements has set the maximum permissible occupational radiation exposure for a pregnant anesthesia provider at 5 mSv (5 mSv is the approximate amount of radiation exposure in an abdominal CT without contrast or a nuclear medicine bone scan). Other committees including the American College of Radiology Resolution and the American College of Obstetrics and Gynecology state that exposures less than 50 mSv are not associated with adverse fetal outcomes.

Obviously, the pregnant anesthesia providers should avoid intraoperative radiation exposure. However, if radiologic imaging is necessary, the use of protective lead shielding and increased distance from the radiation source can minimize in utero exposure. In a study of orthopedic surgeons, fetal radiation dose was approximated by measuring radiation on a dosimeter worn on the abdomen underneath a standard thickness lead apron. Estimated fetal radiation exposure ranged from 0.014 to 0.044 mSv for common procedures. In addition, doubling the distance from the radiation source reduces exposure by approximately a factor of four.

## Methyl Methacrylate

Methyl methacrylate (MMA) is a volatile compound, with a distinct acrid odor, used in the formation of bone cement. Concern over the teratogenic effects of in utero MMA exposure was highlighted by rat studies in the 1960s demonstrating growth retardation, skeletal malformations, and fetal death at high doses. Although MMA causes irritation of the skin, eyes, and mucous membranes, the human fetal effects have not been well defined. Several studies have investigated levels of MMA exposure in the operating room. Although MMA is measurable in the air during orthopedic procedures, serum

samples of operating room personnel show no evidence of MMA. The absence of measurable systemic levels of MMA suggests minimal potential for adverse fetal effects. However, since the safe dose of in utero MMA exposure has not been definitively determined, it is reasonable for pregnant anesthesia providers to avoid intraoperative MMA exposure.

## Conclusions

Although exposures inherent to the operative room environment may (will!) incite worry in the pregnant anesthesia provider, the incidence of adverse fetal effects is low. The long history of successful pregnancies in anesthesia personnel provides further reassurance. Most departments and colleagues are very supportive of the pregnant anesthesia provider, often taking care to avoid assigning her to rooms with radiation or MMA exposure. As essential with any anesthesia practice, good communication with colleagues is key.

### TAKE HOME POINTS

- **Always** use personal protective equipment and universal precautions to avoid exposure to blood-borne pathogens.
- Levels of waste inhaled anesthetic agents that meet OSHA requirements probably pose little increased risk to the fetus. Consider avoiding cases involving inhalational inductions, uncuffed tubes, or unscavenged rooms.
- Avoid cases with radiation if possible. When exposed to radiation, wear wrap-around lead, use a protective lead shield, and increase distance from the radiation source.
- Avoid cases with MMA if possible. However, if unavoidable, the risk of teratogenicity is low.

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# The Pregnant Anesthesia Provider (and New Adoptive Parent)—Part 2

Elliza M. Chen, MD and Colleen Moran, MD

Balancing family and career has long been a challenge in practicing medicine. The excitement of a new family member is often met with an equal amount of stress and anxiety. Common concerns include inability to spend sufficient time with a new child, financial strain of time off work and paying for childcare, possible extension of training, falling behind in skills or knowledge, discrimination in hiring, and ability to breastfeed after returning to work to mention only a few. These issues weigh heavily on the minds of many new and repeat parents.

## Family Medical Leave Act

While timing of pregnancy and adoption are highly personal, you do have valuable and important protections under law. The federal government currently mandates job-protected, unpaid leave for qualifying family and medical reasons. This includes pregnancy, adoption, foster care, and personal or family illness. The Family and Medical Leave Act (FMLA) ensures new parents up to 12 weeks of unpaid leave with benefits if the employee has been employed for at least 12 months and worked at least 1,250 hours in the past year. There are exceptions, including employers with less than 50 employees. Additionally, if you and your spouse are coemployed by the same employer you may be required to share your 12 weeks of FMLA time. You may need to provide at least 30 days' advanced notice. Importantly, many states and employers offer more generous FMLA benefits which your human resources department or benefits office should be able to clarify. Rules regarding the use of sick time or vacation days for parental leave are employer dependent. Short-term disability benefits vary widely, so inquire with your benefits office to see if you are entitled to compensation. Be sure to investigate whether your healthcare benefits and malpractice insurance costs will be covered during your leave.

Resident physicians should consult with their graduate medical education (GME) office regarding parental leave. Residents are often allowed more generous extended family or medical leave, but may be required to extend training.

## Other Legal Protections

The Patient Protection and Affordable Care Act offers protections to lactating mothers. Employers must provide "reasonable break time for an employee to express breast milk for her nursing child for 1 year after the child's birth each time such employee has need

to express the milk." This workplace lactation space must also be "a place, other than a bathroom … free from intrusion from coworkers and the public." Many hospitals have dedicated lactation rooms available with hospital grade pumps.

There are additional protections for pregnancy complications including bed rest, gestational diabetes, and postpartum depression under the federal Americans with Disabilities Act (ADA) and the Pregnancy Discrimination Act. Should any of these more complicated issues be relevant, more information can be found online and in the book You're Pregnant? You're Fired!.

Finally, make sure to seek practical advice regarding parenthood from colleagues who have gone before you. They are a great resource for tips on managing day-to-day struggles from childcare to pumping at work. Although not always easy, there are ways to find work–life balance and there are numerous anesthesiologists who have had safe pregnancies and successfully combined their careers and family life. Congratulations and best of luck on your next life adventure!

## TAKE HOME POINTS

- New parents (birth and adoptive) have protections by law.
- The FMLA ensures new parents up to 12 weeks of unpaid leave with benefits if the employee has been employed for at least 12 months and worked at least 1,250 hours in the past year.
- The Patient Protection and Affordable Care Act offers protections to lactating mothers.
- Benefits for other pregnancy or new-parent issues may be available under the ADA.
- Don't be afraid to connect with and share problems and solutions with your colleagues. There is power in the group!

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## SECTION XIII

# HUMAN FACTORS

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# Introduction

Brian T. Gierl, MD and Catherine Marcucci, MD

This section is one of the most important in the book, we feel, as well as a tribute to the art of anesthesia practice.

The practice of anesthesia can be, and very often is, a stressful and high-conflict endeavor. The operating room and remote anesthetizing sites are the only locations and situations in clinical medicine where two autonomous and independent clinicians must each exercise and discharge their primary responsibilities for the treatment and care of the patient on a simultaneous basis. And these responsibilities and treatment goals may directly oppose each other. For example, the anesthesia provider's goal to maintain vigilance always over the patient is in opposition to the surgeon's need to have the patient covered, turned away from the anesthesia provider, and rotated in the room. And so it goes on from there. Of course, while managing conflict the first person the anesthesia provider needs to "manage the human factors of" is him-or-herself.

Many of the chapters in this section have been revised and updated from the first edition of Avoiding Common Anesthesia Errors. These topics deal with principles that are timeless and always relevant to anesthesia clinicians—for example, the basics of aviation safety, spelling alphabets, and the dangers of sunk costs. But we have also taken the opportunity of our second edition to include some new and interesting topics for anesthesia providers to consider.

At its most basic, the field of Human Factors is about commonsense and relationships. Never go outside the bounds of behavior that you would be hard put to justify to the person on the street (or yourself!) and always treat your relationships (including with yourself!) with the consideration and care they deserve.

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# Understanding the Human Factor

F. Jacob Seagull, PhD

Have you ever accidentally poured orange juice in your cereal instead of milk? Have you ever tried to drive from work to the store and ended up driving home by accident? Most likely you have. Have you ever accidentally put sugar into your shoes instead of talcum powder? Probably not. Why not? **Because "mistakes" do not happen randomly when humans are involved—they occur in systematic patterns. Some are likely, some are not.**

Understanding how people think allows us to understand the types of mistakes that they might make and the types that they are unlikely to make. The study of how people act in the context of work—including the mistakes that they make—is known as "human factors."

Applying the principles of "human factors psychology" to the domain of anesthesia can create an environment in which a serious mistake is much less likely to occur. Giving the wrong drug should be like putting sugar in your shoes, not like putting juice in your cornflakes. Anesthesia has been at the forefront of human factors in the medical domain for a number of years, adopting safety initiatives, making continuous process improvements, attaining advances that significantly reduced the likelihood of adverse events, and the early adoption of simulation in the education of trainees and skills maintenance of experienced providers. Anesthesia has been singled out by the Institute of Medicine as the medical discipline that can serve as a model of "safety culture" and rightfully so.

The concept of human factors has its roots in aviation. It was first used by the U.S. Air Force to help push human performance to the limit in order to beat the enemy. The fighter pilots in World War II were surrounded by advanced cockpit technology in life or death situations—not entirely unlike an anesthesiologist in an operating room. By designing the pilots' environment to support the task at hand, human factors helped give them the edge they needed.

The field of human factors is multidisciplinary, encompassing domains from psychology to engineering to anthropology to computer science and more. Many different aspects of human activity relevant to anesthesiology fall under the scope of

human factors. A few of the more relevant aspects are described briefly in this chapter.

## Decision Making

People make decisions in a very different manner than computers. Instead of using precise calculations, people often use heuristics, or rules of thumb, to decide what to do. Heuristics can be a powerful tool that lets a person make quick decisions when relevant information is incomplete or unavailable. Unfortunately, there are times when using heuristics may lead to systematic biases in decision making, or put more simply, can make a mistake more likely. Human factors psychology has examined a wide array of decision-making aspects, including heuristics and biases. Through the application of human factors principles, one can remediate many common biases, leading to better, safer decisions in critical anesthesia situations.

## Technology Design and Cognitive Ergonomics

In a fighter jet, well-designed avionics displays can mean the difference between a kill and a crash. In anesthesia, clear monitoring displays, easy-to-program infusion pumps, and clearly identifiable syringes and drugs can have a similar effect. Technology designed with human factors' "cognitive ergonomics" considerations can reduce the likelihood of making an error and improve the odds of recovering from adverse events.

## Communication

Human perceptual abilities have their limits and weaknesses. Whether interacting with a piece of technology or with another human, people must take in and make sense of information in the environment and convert the perceptual signals into concepts and knowledge about the world. Application of the principles of human factors can cater to human perception's strengths and compensate for perceptual weaknesses, facilitating clear, concise, and error-free communication.

## Environmental Design

It is easier to place a central line in a quiet, calm, well-lit room than in the shadow of a noisy code team during an emergency resuscitation. Environmental factors such as noise, lighting, and work space layout can influence the margin of safety in which care is provided.

## Complex Systems

Each individual artifact with which we interact undoubtedly influences the ultimate success or failure of our endeavors. However, beyond these individual influences, there

is an overarching interaction among the multitude of systems, artifacts, and people that can have an influence greater than the sum of the parts. Ultimately, it is most often a system failure, and not a failure in the function or design of an individual artifact, that leads to catastrophic failure and adverse events in anesthesia. Human factors address issues arising from the complexity of highly coupled technical systems, and can help offer effective system design, or even impart effective strategies for interacting with flawed systems.

Understanding some key aspects of human factors can provide you with points of leverage in critical situations, and perhaps more importantly, can help you prepare yourself properly to avoid critical situations before they arise. The chapters in this unit touch on a small selection of relevant topic areas where consideration of human factors can contribute to safe and effective practice of anesthesia care.

## TAKE HOME POINTS

- Mistakes do not happen randomly but rather in systematic patterns.
- The Institute of Medicine paper that singled out anesthesia as the medical discipline that can serve as a model of "safety culture" is an important document that is now driving much of the pay-for-performance/quality movement.
- Anesthesia providers at all levels will increasingly be called on to understand, master, and integrate the basic principles of human factors psychology into the delivery of anesthetic care.

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# Minimize Errors in Anesthesia: Lessons Learned From Aviation

Stephen J. Gleich, MD and Juraj Sprung, MD PhD

The practice of anesthesiology and the operation of commercial aircrafts share key characteristics, including effective communication and situational awareness. The importance of Crew Resource Management was illustrated in a major airline disaster. In 1978, a commercial airliner experienced a minor landing gear indicator malfunction, which required the crew to troubleshoot the problem before landing. The aircraft was low on fuel, and even with the installation of new digital fuel gauges and warnings, the three-person crew did not realize the low fuel situation until the engines began to fail. The flight circled the airport until the plane ran out of fuel and crashed. The experienced crew was focused on resolving the landing gear problem, did not effectively communicate, lacked situational awareness, and did not identify another developing adverse event, even in the presence of modern technology.

Following this airline crash, Crew Resource Management (CRM), also known as crisis resource management, was originally developed for the aviation industry. CRM emphasizes a comprehensive approach to managing a situation in high-stress, high-risk environments. CRM includes human factors such as leadership, interpersonal communication, delegation, and role clarity. In addition, CRM promotes maintaining situational awareness and utilizing all available resources in a crisis situation. Importantly, CRM fosters a unified environment with effective communication in which junior personnel are unconstrained about alerting others when something is amiss.

## Application of Aviation-Adopted Crew Resource Management to Anesthesia Practice

The widespread adoption of CRM principles can greatly enhance management of crises and adverse events in aviation and in the perioperative setting. CRM training and utilization in the aviation industry is commonplace. Medicine, however, has been slower to adopt formal CRM training. Recent CRM training programs such as the Veterans Affairs (VA) Medical Team Training and the U.S. Department of Health and

Human Services TeamSTEPPS® programs are greatly enhancing the practice of CRM in medicine.

CRM, when applied to anesthesiology, includes several key components (Fig. 261.1), including:

- Calling for help early (e.g., calling a "Code Blue" early when a patient is deteriorating)
- Anticipate and plan (e.g., schedule a preoperative briefing with the surgeon and discuss potential complications of the case, including blood loss)
- Know the environment (e.g., know where all the emergency equipment is located)
- Use all available information (e.g., utilize all resources—printed and human experts)
- Allocate attention wisely (e.g., maintain vigilance, avoid distractions, observe the "sterile cockpit")
- Mobilize resources (e.g., calling blood bank early for massive transfusion)
- Use cognitive aids (e.g., using a checklist for rare intraoperative events, such as malignant hyperthermia to assure all critical treatments are performed)
- Communicate effectively (e.g., verbally repeating all drug doses to verify correct dose drawn up and administered)
- Distribute the workload (e.g., delegate tasks)
- Establish role clarity (e.g., team leader assigns specific roles to specific team members)
- Designate leadership (e.g., always know who is the team leader)

Certain behaviors in the operating room increase risk to patients. According to Helmreich, failures of CRM can be divided into four categories: communication, leadership, conflict, and vigilance.

## Communication

- Failure to inform the team of the patient's problem (e.g., surgeon fails to inform anesthesiologist of surgical bleeding before a decrease in blood pressure is observed).


**Figure 261.1.** Key Points of Crisis (Crew) Resource Management. (©2008 Diagrams: S. Goldhaber-Fiebert, K. McCowan, K. Harrison, R. Fanning, S. Howard, D. Gaba. Originally published in: Goldhaber-Fiebert SN, Howard SK. Implementing emergency manuals: Can cognitive aids help translate best practices for patient care during acute events? Anesth Analg. 2013;117(5):1149–1161.)

## Leadership

- Failure to establish leadership in the operating room team (e.g., anesthesiologist does not direct the actions of other team members during an intraoperative cardiac arrest).

## Conflict

- Overt hostility and frustration (e.g., patient deteriorates while surgeon and anesthesiologist argue over who is responsible for newly developed tension pneumothorax).

## Vigilance

- Failure to monitor situation and other team member activities (e.g., distracted anesthesiologist fails to detect decrease in blood pressure after a monitor power failure; anesthesiologist treats hypertension while the transducer is "sitting" on the floor).
- "Sterile cockpit:" avoid all nonessential communication (conversations) during critical portions of anesthesia induction, emergence, and any periods of instability during anesthetic maintenance.

CRM applied to the anesthesia and the operating room team encompasses the effective integration and practice of these components. The practice of anesthesiology is amenable to improvement, and many elements of safety enhancements in the aviation industry are applicable. Integration of CRM practices in every operating room is vital to ensure prevention and effective management of adverse events.

### TAKE HOME POINTS

- The similarities between the aviation and anesthesia industries are not just a cliché!
- Every anesthesia practitioner should become truly expert in the principles and practice of Crisis Resource Management.
- In any crisis or clinically urgent situation, you must know how to establish communication, leadership, and vigilance as well as avoid conflict.

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# Eliminate Communication Errors by Using a Spelling Alphabet and Spoken Digits

Michael Carrigan, MD, Brian T. Gierl, MD, and Catherine Marcucci, MD

A young resident was about to deliver anesthesia in a chaotic emergency situation. The operating room (OR) desk paged her in the cafeteria to tell her that a patient was being emergently transported to the OR with a carotid blowout; a surgical intern was riding on the stretcher to apply pressure to the bleeder. She was told there were blood products in the blood bank, but that she had to call down there stat and let them know what to pack in the cooler. The problem was, she didn't know the name of the patient. She asked the OR desk to identify the patient, but due to background noise in both the OR and the cafeteria, she couldn't discern the name. She realized it might be Atkins, it might be Adkins, or it might be Adams. She just couldn't hear. She asked several times, each time a little louder. The OR desk replied several times, each time a little louder and each time equally indiscernible. As panic started to set in, she suddenly heard, on the telephone, the calm voice of her CRNA colleague (who had served as a U.S. Air Force medic in Vietnam), saying slowly, "The patient is Alpha-Delta-Kilo-India-November-Sierra." Armed with the correct information, she placed the appropriate call to the blood bank. Mr. Adkins required four units of packed red blood cells, no plasma or platelets, and did fine.

Professionals in many theaters utilize a spelling alphabet to eliminate the uncertainty in unclear speech. People commonly hear things second hand, mispronounce words/names, use communication devices with less than crystalline transmission, and speak too fast for others' ears. In addition, non-native English speakers may pronounce words differently from those speaking "American English" and may be unable to pronounce specific sounds. Many Chinese and Japanese have difficulty pronouncing "L" and often substitute "R" which has (unfortunately) been fodder for comedians for decades.

Spelling alphabets are commonly called military alphabets, aviation alphabets, radio alphabets, telegraph alphabets, or police letters. They are often incorrectly referred to as "phonetic alphabets," which are written representations of spoken sound as opposed

to spoken representations of written symbols. There are slight variations among communities, but each spelling alphabet uses a single phonetically distinct word to replace the name of the letter with which it starts. They have their origins deep in military and communications history, and have been used at least since the beginning of the 20th century. They arose with the advent of aviation as military radios were plagued by static and lack of clarity. As so many letters in the English language are phonetically similar (e.g., B, C, E, T, D, P), a single unclear letter would confound reliable relay of information and direction, leading to unreliable mission execution. Spelling alphabets are used in at least 30 languages (from Finnish to Urdu), and a numeric code usually exists as well.

OR's are noisy places, often increasingly so in times of stress. Decibel levels have been measured under a variety of situations and for different types of procedures. The "average" noise level in a routine case may range 55 to 80 dB with peak levels reaching 120 to 140 dB, similar to the intensity of boiler/industrial rooms and high enough to pose an occupational hearing loss risk to OR personnel.

OR noise is known to have detrimental effects on anesthesia providers. In a study by Murthy et al., when anesthesia residents were exposed to a 90-minute cassette of OR noise at 77 dB, their speech reception threshold and speech discrimination were diminished, which led researchers to conclude that there is a marked decrease in the ability to discriminate spoken words at ambient OR noise levels. The use of a spelling alphabet may, therefore, have the same efficacy for anesthesia providers as for the military and pilots. The residents in the study also had lower scores on tests for mental efficiency and short-term memory. In addition, as demonstrated by Way et al., speech discrimination decreases with both noise level and task responsibilities, which are routine challenges for anesthesia providers. Thus, anything to simplify communication can allow mental resources to be better utilized on the tasks at hand rather than the clarification of clerical errors. The spelling alphabet used in World War II was modernized in the 1950s, as military pilots returned to their civilian careers. The most commonly used alphabet today is known as the international radiotelephony or NATO spelling alphabet (Table 262.1). It is simple to memorize and easy to use.

**Table 262.1 ■ Standard Spelling Alphabet**

| Letter | Spoken |
|---|---|
| A | Alpha |
| B | Bravo |
| C | Charlie |

| | |
|---|---|
| D | Delta |
| E | Echo |
| F | Foxtrot |
| G | Golf |
| H | Hotel |
| I | India |
| J | Juliet |
| K | Kilo |
| L | Lima |
| M | Mike |
| N | November |
| O | Oscar |
| P | Papa |
| Q | Quebec |
| R | Romeo |
| S | Sierra |
| T | Tango |
| U | Uniform |
| V | Victor |
| W | Whiskey |
| X | X-ray |
| Y | Yankee |
| Z | Zulu |

Similar to the use of the spelling alphabet, saying the individual digits in a number can eliminate misinterpretation of otherwise easily confused numbers such as fifty and fifteen. So confirming blood unit number WSTR05514 as whiskey-sierra-tango-romeo-zero-five-five-one-four leaves little doubt in the ears of the listener as to the identity of the product.

## TAKE HOME POINTS

- The noisy OR introduces the possibility of verbal miscommunication, which is one of many vital contributors to preventable adverse events, and these simple habits can help protect patients.
- The spelling alphabet is a time-tested method of more accurately transmitting letter-based information.
- Saying individual digits of a number will likewise improve succinctness and clarity in communications.

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# Don’t Ignore Your Intuition

F. Jacob Seagull, PhD and Catherine Marcucci, MD

Something doesn’t feel right. You can’t put your finger on why, but something about the patient’s status just seems wrong. You look at the monitors and there are no alarms going off, and the patient’s vital signs appear to be normal … but things just don’t feel right. What should you do?

The answer is that there is no one best answer.

When you are able to gather data and analyze your options, you can spend time seeking additional information, running tests, and using tools such as decision aids to help you. People can be very accurate making snap decisions using what Daniel Kahneman called “System 1 thinking,” which relies on rapid recognition, automatic information processing (like reading), or retrieval from memory. For more complex problems, we use slower, more deliberative processes, which Kahneman calls “system 2 thinking,” like searching for information, and understanding complex situations. Each type of thinking has its own limitations, and is subject to its own biases. Using decision aids and standard protocols for treatment can avoid some of the common biases that plague human decision-making powers, as discussed in Chapter 274. If you have time, don’t trust your gut.

However, anesthesiology often operates under time pressure and in situations where complete data are not available. When time is short and you suspect that a problem is developing, trusting your intuition may be the best option.

Intuition is increasingly recognized as an important component of decision making. But what is intuition, exactly? It is the ability to judge a situation on the basis of information that is activated in memory but not consciously retrieved. People making decisions often recognize patterns of information without consciously naming those patterns.

There is little or no information on intuition in the anesthesia peer-reviewed literature. However, since the 1990s, researchers have looked at its role in a number of other areas including firefighting, industrial and chemical processing plants, corporate and business planning, nursing units, and pilot and military situations (the nursing and military studies are perhaps the most relevant to anesthesia care). Gary Klein is one

author in the field of recognition primed, or "naturalistic," decision making who has published a number of interesting recent studies. He estimates that as many as 95% of decisions in naval aviation (specifically those of the antiaircraft warfare operators in the AEGIS Cruiser) involve recognition of a specific situation, not a choice between alternative actions. He has also studied the phenomenon of neonatal intensive care nurses "sensing" when a baby's health was deteriorating before any tests or monitors picked up on the problems. Klein was actually able to determine what cues the nurses were subconsciously picking up on in making their "intuitive" diagnoses. Also, although the exact mechanisms underlying intuitive judgments are still under discussion, it has been established that study subjects can make intuitive judgments about linking coherent or disqualifying incoherent data triads in as little time as a few seconds.

Similarly, anesthesia providers should be aware of the role that intuition may play in the delivery of anesthesia care and the possible consequences of ignoring it. The authors suggest that there are several clinical situations where a flash of intuition commonly occurs.

The first of these involves assessment of the patient's overall health status. What you say to your anesthesia colleagues is important—a simple comment of "this guy doesn't look so perky" or "it's not going to be so easy to wake this lady up" probably reflects a set of subtle clinical signs, including the appearance of mucous membranes, skin turgor, mental status, and respiratory pattern. The second circumstance involves airway evaluation. Often, the first glimmer of an impression about an airway proves to be the most reliable, formed just in the instant when you catch a glimpse of the patient through an operating room window or as he or she comes into the room. Often, what you think seems ridiculously simple, such as "that's a really big tongue" or perhaps you feel a slight sense of anxiety. The third situation arises when you thought "this patient needs an arterial line, definitely" and then have trouble with placement. Sometimes, a surgeon will ask whether the patient really does need the arterial line and then a discussion begins that may end in changing the plan.

Trusting your intuition does not mean ignoring the data that you have, or data that are available to you. Intuition stems from information gathered, processing the right aspects of the data, and recognizing the pattern created. Intuition is not a magical gift of clairvoyance but rather a skill that can be developed through practice and experience. One way of developing intuition is by gaining a wide array of divergent experiences to foster recognition.

Certainly, intuition cannot and should never substitute completely for a carefully thought out and articulated anesthetic plan that is based on the available outcome-based evidence. In fact, a part of intuition stems from having a good contingency plan for unexpected events—with a plan, you will be primed to look for relevant cues and able

to respond by confirming your "gut" with data. Most experienced anesthesia providers, however, can relate cases and circumstances in which they ignored that first flash of intuition to their later regret.

## TAKE HOME POINTS

- Intuition is real and can be an important component of decision making.
- Intuition is not just guessing, it is based on subconscious pattern recognition.
- Trusting your gut is not the same as ignoring evidence—intuition can help you when no other data are available.
- Varied experiences and careful contingency plans help you use "intuition" to recognize situations correctly and respond to them appropriately.

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# Ethics in Anesthesiology Practice

Harriet W. Hopf, MD

Anesthesiologists face a variety of ethical issues in daily practice, with the added challenge that they often have to make decisions within a short time frame and usually without any prior relationship with their patient. This chapter will review several approaches to ethical decision making in medicine, with a discussion of special considerations in anesthesia practice. Cases will be used to explore approaches in commonplace situations where complex decision-making is required.

## Principles

**Four principles are often described as the basis for medical ethics, including beneficence (do good), nonmaleficence (do not do harm), respect for autonomy, and distributive justice.** The three components of autonomy include independence from controlling influences, understanding, and the capacity for intentional actions. Distributive justice requires fairness, entitlement to care, and equitable delivery. These principles have limitations. For example, how do you decide which principle takes precedence? Is harm ever acceptable in the pursuit of benefit? Case-based ethical reasoning, or casuistry, applies a pragmatic framework to decision-making, somewhat analogous to evaluating precedents in law. In evaluating any case, four areas are analyzed: medical indications, patient preferences, quality of life, and context. Given that personal values differ and provide different starting points for discussion of ethical issues, the goal of case-based reasoning is for all involved to reach agreement on the best decision.

**Table 264.1 ■ American Medical Association Principles of Medical Ethics (Revised 2001)**

**Preamble**

The medical profession has long subscribed to a body of ethical statements

developed primarily for the benefit of the patient. As a member of this profession, a physician must recognize responsibility to patients first and foremost, as well as to society, to other health professionals, and to self. The following principles adopted by the American Medical Association are not laws, but standards of conduct that define the essentials of honorable behavior for the physician.

**Principles of Medical Ethics**

I. A physician shall be dedicated to providing competent medical care, with compassion and respect for human dignity and rights.

II. A physician shall uphold the standards of professionalism, be honest in all professional interactions, and strive to report physicians deficient in character or competence, or engaging in fraud or deception, to appropriate entities.

III. A physician shall respect the law and also recognize a responsibility to seek changes in those requirements which are contrary to the best interests of the patient.

IV. A physician shall respect the rights of patients, colleagues, and other health professionals, and shall safeguard patient confidences and privacy within the constraints of the law.

V. A physician shall continue to study, apply, and advance scientific knowledge, maintain a commitment to medical education, make relevant information available to patients, colleagues, and the public, obtain consultation, and use the talents of other health professionals when indicated.

VI. A physician shall, in the provision of appropriate patient care, except in emergencies, be free to choose whom to serve, with whom to associate, and the environment in which to provide medical care.

VII. A physician shall recognize a responsibility to participate in activities contributing to the improvement of the community and the betterment of public health.

VIII. A physician shall, while caring for a patient, regard responsibility to

the patient as paramount.

IX. A physician shall support access to medical care for all people.



The American Medical Association (AMA) developed Principles of Medical Ethics (Table 264.1; most recent revision in 2001) as an ethical guide for physicians. The American Society of Anesthesiologists (ASA) incorporated these principles into Guidelines for the Ethical Practice of Anesthesiology. These guidelines include principles specific to anesthesiologists related to ethical responsibilities to patients, medical colleagues, healthcare facilities, themselves, and communities and society. The most recent version of all ethical guidelines developed by the ASA can be found at https://www.asahq.org/resources/ethics-and-professionalism.

## Ethics and Anesthesiology

Anesthesiologists have made major contributions to the field of medical ethics. In the mid-1800s, as anesthetics came into use, relief of pain was viewed with suspicion as interference in the divine plan. John Bonica, who established the first multidisciplinary pain clinic in the 1960s, was among the first to recognize pain relief as a basic human right. Henry Beecher published a landmark article in 1966 that was the first to advocate for human subject protections in clinical research, including institutional review boards and informed consent. His work helped to reshape medicine from a paternalistic culture to a focus on patient autonomy. The U.S. Congress passed the Patient Self-Determination Act in 1990, which codified patient autonomy in federal law. Under the law, patients must be informed of their rights to consent to and refuse medical therapy, recognizing that informed consent requires the right of informed refusal. In 1991, Robert Truog published a landmark evaluation of the routine practice of suspending Do Not Resuscitate Orders (DNR) perioperatively as a violation of patient autonomy. This publication prompted the ASA Ethics Committee to develop Ethical Guidelines for the Anesthesia Care of Patients with DNR Orders or Other Directives that Limit Treatment, first approved by the House of Delegates in 1993. The ASA Ethics Committee also led the way in considering the ethics of physician participation in legal executions. The arguments revolved around the conflict between beneficence (ensuring a "humane" death) and nonmaleficence. The resulting Statement on Physician Nonparticipation in Legally Authorized Executions, approved by the ASA House of Delegates in 2006 and reaffirmed in 2016 declared that "capital punishment in any form is not the practice of medicine" and concluded that "ASA strongly discourages participation by

anesthesiologists in executions." In 2010, the American Board of Anesthesiology became the first physician organization to introduce punitive actions, including loss of certification, for anesthesiologists who do so.

## Cases

**Case 1:** You meet your patient in preoperative holding, an 82-year-old woman with well-controlled hypertension and no other medical problems scheduled for an urgent laparoscopic appendectomy. She continues to live in her own home and is active in the local community. You plan a general anesthetic with endotracheal intubation. You notice she has an Advance Directive in the chart that includes Do Not Resuscitate/Do Not Intubate (DNR/DNI). How do you discuss the advance directive with the patient? How does it affect your anesthetic plan?

**Discussion:** It is not uncommon for surgical patients to have an advance directive or in-hospital orders that specify "Do Not Resuscitate" or otherwise limit treatments. The practice of anesthesiology, however, is intrinsically a practice of resuscitation. Patients are routinely intubated for general anesthesia, and anesthetic agents frequently cause hypotension that is straightforward to treat with vasopressors. For many years, this ethical dilemma was solved by automatically suspending these orders. Unfortunately, this approach abrogates patient autonomy. The ASA Committee on Ethics guidelines recommend revising policies that automatically suspend DNR orders to "address a patient's rights to self-determination in a responsible and ethical manner." The DNR order must be reevaluated in collaboration with the patient and patient's family, the surgeon, and the anesthesiologist. **The ASA guidelines identify three options: the patient may (1) opt to suspend the DNR order and allow for a full attempt at resuscitation during the procedure and for a defined and mutually agreed period after; (2) opt for limited resuscitation, using a checklist to identify specific procedures (e.g., chest compressions, defibrillation, tracheal intubation, mechanical ventilation, fluid resuscitation, or vasopressors) that they would or would not accept; or (3) define resuscitation in terms of outcomes, rather than procedures, with the details left to the anesthesiologist's judgment, taking into consideration the patient's goals and values.** The third option is challenging in the perioperative context, because it requires in-depth, time-consuming discussions. Hall et al. suggest early preoperative anesthesiologist involvement (i.e., the Perioperative Surgical Home) as a mechanism for advancing such patient-centered decision making, at least for patients undergoing elective procedures. In the presented case, because anesthetic management for laparoscopic appendectomy routinely includes tracheal intubation and mechanical ventilation, and there is a high likelihood of hypotension after induction in

an acutely ill and likely dehydrated patient, which would normally be treated with fluid resuscitation and vasopressors, it would be reasonable to stipulate that these procedures would be used. The patient might decide full suspension was reasonable, or specify that chest compressions or defibrillation should not be used in the event of cardiac arrest, or ask that the anesthesiologist pursue full resuscitation if they believed full recovery was possible, but not if they thought the outcome of resuscitation would be poor. Alternately, after discussion with and agreement from the surgeon, the anesthesiologist could offer the patient the option of open appendectomy under spinal anesthesia, which would remove the need for intubation and ventilation.

**Case 2:** You are called by the nurse in preoperative holding because your patient, a 35-year-old, otherwise healthy woman scheduled for anterior cruciate ligament repair is refusing to provide a urine sample for the pregnancy test that is routine in your practice for all women of child-bearing age. When you meet the patient, she is incensed. She explains that she is a lesbian and knows for a fact she is not pregnant, and that she finds the demand invasive and unreasonable. Would you proceed with the surgery? Would your decision be different if she were scheduled for a hysterectomy?

**Discussion:** Preoperative pregnancy screening is a common practice. Screening should be based on the risk of fetal harm. Some surgeries, such as those involving the uterus or potentially disrupting uterine blood flow, do pose a risk to the fetus. Exposure to x-rays or teratogenic medications would also pose a risk. No currently used anesthetic agents have known teratogenic effects, but the published literature is inadequate to determine whether there are adverse neurodevelopmental effects on the fetus. Thus, pregnancy testing should be offered to female patients of childbearing age if the result would alter the patient's medical management (e.g., cancellation of an elective procedure). Coercive screening, that is, cancelling surgery if a patient refuses, however, violates patient autonomy. The medicolegal risks related to preoperative pregnancy testing are quite small. **Only 7 of 10,500 claims in the Anesthesia Closed Claims Database relate to undiagnosed pregnancy.** In three claims for miscarriage, no pregnancy test was performed; the claim resulted in a payment only in a case where a hysterectomy was performed in the context of an unrecognized pregnancy. In four claims for miscarriage, a pregnancy test was performed, but the anesthesiologist failed to check the (positive) result; three of the four claims resulted in a payment. The ASA Pregnancy Testing Prior to Anesthesia and Surgery guidelines, approved by the ASA House of Delegates in 2016, recommend that "pregnancy testing be offered to female patients of childbearing age and for whom the result would alter a patient's management," that informed consent for such testing should be obtained, and that pre-anesthetic educational materials should be provided to facilitate informed decision-making by the patient. In

the presented case, the patient should not be required to have a preoperative pregnancy test. She should be provided educational materials and the anesthesiologist should discuss the risks, benefits, and alternatives to pregnancy testing as part of obtaining informed consent. If she gives an informed refusal, the surgery should proceed. If the patient were scheduled for hysterectomy, however, a preoperative pregnancy test would be required, because of the certain risk of fetal harm in the case of an undiagnosed pregnancy. If the patient refuses, the surgery should be cancelled.

## Summary

Application of ethical principles in anesthesiology is challenging because the anesthesiologist usually does not have an existing relationship with the patient and time pressures interfere with complex and detailed discussions with the patient, in the context that the patient has usually already made a decision to have surgery. The principles of beneficence, nonmaleficence, autonomy, and entitlement to care provide a framework for ethical decision-making. Patient preferences, values, and goals should always be taken into consideration. ASA Committees, particularly the Ethics Committee, have deliberated on a number of common clinical scenarios and developed practical guidelines that support the ethical decision-making efforts of anesthesiologists. Take the time to review them and know them before the fact, as well as the ethics guidelines of your own hospital. Always approach any ethical situation with the utmost kindness and patience toward the patient and family. Never show anger or impatience regarding the fact that an ethics question has arisen. At the same time, do not hesitate to ask for additional time if you feel you need it. **Never let somebody else (the surgeon?) make your decision for you.** You must be a full participant in the ultimate decision and arrangements.

### TAKE HOME POINTS

- The four principles of medical ethics are: beneficence (do good), nonmaleficence (do not do harm), respect for autonomy, and distributive justice. Distributive justice is defined as the distribution of goods in society in such a way that incidental outcomes do not arise.
- The discipline of medical ethics developed alongside of and as part of the development of the specialty of anesthesiology.
- Certain ethical decisions arise commonly, for example, DNR orders and planned or necessary medical interventions that are deemed “invasive” by the patient. Much help is already in place for these situations. But not if you don’t or won’t access it.
- The most recent version of all ethical guidelines developed by the ASA can be found

at https://www.asahq.org/resources/ethics-and-professionalism

- Seek to continually update your ethics knowledge base. Read about recent cases and decisions and attend all the ethics lectures and presentations you can get to.
- Be kind to your patients, always. Never do anything that could be construed as being punitive to a patient because they present you with an ethical situation that requires a decision.

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# Know When to Stop—Anesthesia Providers Have Got to Know Their Limitations

Brian T. Gierl, MD, F. Jacob Seagull, PhD, and Catherine Marcucci, MD

**In other words, patients can be seriously injured not because the anesthesia providers can't do something but because they can't stop trying.**

For example, here is a situation that must be avoided at all costs: An anesthesia team is genuinely surprised and has unexpected difficulty intubating a patient. A mask airway is established, and one more attempt is made to intubate the patient. A reasonable safety limit is set—the team members say to each other, "Okay, you are going to try once more and I am going to try once more and then we are going to stop." However, by this time, there are several other providers in the room who have brought additional airway equipment. When the two additional attempts are unsuccessful, the safety limit is disregarded in order to keep trying. Later, albeit with great difficulty, the airway is managed by mask and the patient is awakened. Unfortunately, such difficulty and violation of safety limits can occur with airway attempts, regional block techniques, and invasive line placements. The question is why? **Why do high-skilled practitioners who know the risks set a limit and then go over it?**

There are two central explanations for this phenomenon, both of which deal with people's tendency to consistently make decisions that are not rational. There is a whole field of psychology, formally called the psychology of decision making, that explores the consistent ways in which people's minds are irrational. Here are two examples, both of which are classics in decision making.

The first is the concept of "sunk cost." Sunk cost is the initial investment in an endeavor—the cost can sometimes be financial, but it can also consist of effort or time invested. **Having invested in something, people are much less willing to walk away from it, even if the gain from further investment is not worth the risk.** The process is sometimes called "throwing good money after bad." Once a bad investment is made, extreme (often futile) measures will be undertaken to turn the loss into a gain. The proper strategy is to cut one's losses. One common example is the "sunken cost" of time spent attempting to thread a catheter—perhaps a femoral arterial line that just won't

thread, but you need it to start the case and now the surgeon is staring at you and you feel that you are just about to get it to thread on the next attempt. It is much easier for a second anesthesiologist to enter a room after someone else has given three attempts and say, "Okay, let's change tactics," than it is for an individual who has made attempts to "admit defeat."

Second, a more global theory of decision making under uncertainty is prospect theory, which generally revolutionized decision-making theory. One tenet of prospect theory is that people are much more willing to gamble and take chances to avoid loss than they are to gamble to reap gains. The idea is that "losses hurt more than gains comfort." People are actually quite sensitive to their perception of whether something is a loss or a gain. One way of countering this tendency to be biased is to "reframe" the decision (e.g., "You aren't losing a daughter, you are gaining a son-in-law."). So, think of framing the failed intubation as a "gain" of a preserved airway instead of a "loss" of the previous efforts; you are more likely to get someone to change his or her mind and abandon the risky persistence. "Putting the patient first" may help.

Another potential reason for poor decision making is allowing one's ego to dictate their decision making. Classically, "ego-bias" refers to less experienced providers believing that their patients will have better outcomes than those suggested by outcome data from similar patients. Here, we are referring to another form of egoic decision making in which the provider is simply set on declaring their success with a certain technique. You've probably witnessed someone struggle with intubation via direct laryngoscopy with a poor view without trying a different technique solely because they wanted to succeed with their initial method. When a direct laryngoscopy provides a poor view, the consciously thinking provider would plan to improve muscle relaxation or reposition the patient, change laryngoscope blades, or use an alternative form of video laryngoscopy or fiberoptic intubation rather than continue to struggle and risk laryngeal trauma by attempting to pass an ETT with a poor view—or worse, no view of the vocal cords at all!

The **Vortex Approach** (https://vortexapproach.org/) is a guideline to airway management that is based on the idea that if an attempt at ventilation—either bag-mask ventilation, LMA placement, or intubation—fails to provide a means to oxygenate, you then have to decide whether to optimize that method or move on to another method. **After three attempts of one method—with an optimization before each re-attempt—you must move on to another method of intubation or you violate the guideline of the Approach.** The five optimizations are patient positioning/laryngeal pressure, adjuncts such as Eschmann stylets or oral airways, changing to another size (MAC 4 for MAC 3 laryngoscope blade) or device type (Miller for MAC blade), suctioning foreign material or increasing oxygen flow, or revisiting the adequacy of muscle relaxation.

Another classic example is recurrently attempting central venous access using a landmark technique despite multiple failed attempts to either obtain venous blood flow or a failure to thread the catheter into the vessel of choice. Sensible approaches in this case might include changing patient position, accessing a different vessel as appropriate, or changing from a landmark-based to an ultrasound-based technique if an ultrasound is available. Given that CVC cannulation is less time-sensitive than airway management, one could simply ask an associate to obtain access using a method that they see fit given the difficulty that has already been encountered. Unless you and your ego are so set on achieving successful cannulation of THAT vein at THAT site that you cannot move on to another technique.

What can you do in any of these situations? Think of the patient. Redefine failure as creating injury or bodily insult—rather than your inability to succeed—and avoid failure. Bring in a fresh pair of eyes—someone who has not "invested" in the situation and who can think in an unbiased manner. Last, understand that futile persistence is itself a loss of good practice.

## TAKE HOME POINTS

- Practitioners in all fields, including anesthesia, can have a tendency to consistently make irrational decisions.
- Be aware and understand the concept of sunk cost—having invested in something, people are much less willing to walk away from it, even if the gain from further investment is not worth the risk.
- Prospect theory states that people are much more willing to gamble and take chances to avoid loss than they are to gamble to reap gains. The idea is that "losses hurt more than gains provide comfort."
- When you find yourself in a difficult clinical situation that involves failed attempts at a procedure, including intubation, keep these principles in mind. Bring in unbiased practitioners to help you make the decision to stop if necessary.

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# Before You Press Play, Let's Talk About Music in the OR

Lisa MacBeth, MD, Toby N. Weingarten, MD, and Juraj Sprung, MD PhD

For millennia, people have listened and enjoyed music for entertainment as well as a distraction from daily troubles and as a means to relax and relive stress. It is no surprise that even as early as 1914, a surgeon described how music from a phonography provided therapeutic distraction during medical procedures performed under local anesthesia. Since then, surgery has evolved, as has the evidence for music in the operating room. Although music has beneficial effects, it also can impact communication and performance of the procedural and anesthesiology teams.

Many randomized trials have found that patients prefer to listen to music during procedures performed under local anesthesia or sedation. Listening to music with headphones lowered postoperative anxiety scores among patients with moderate to severe preoperative anxiety undergoing ambulatory gynecologic procedures under sedation. Women undergoing Caesarean section had lower anxiety and higher satisfaction with their experience, when they were provided music therapy. In addition, music therapy has been found to not only modulate physiologic stress but also reduced plasma cortisol and natural killer cell levels during ambulatory surgery, and this effect was augmented when patients selected their own music. In addition to reducing anxiety, potential analgesic and analgesic effects of music have been investigated. For example, during regional anesthesia, the Bispectral Index reading was lower in patients listening to music. Supplemental sedation requirements (i.e., propofol or midazolam sedation) are reduced in response to music therapy for procedures performed under neuraxial anesthesia. Further music therapy has been found to decrease postoperative pain. However, some patients find music bothersome and would rather mentally attend to the surgeon and medical procedure.

Many of these studies were conducted with patients listening to music through headphones, which not only delivers music to the patient, but also reduces noise pollution from the operating suite. Music played out loud into the operating room environment has many potential effects on the performance of the surgical and

anesthesia staff. Generally, healthcare staff has a positive attitude toward music believing it improves provider concentration and team communication. These beliefs are more strongly held by nursing staff and resident physicians. **However, music has been shown to decrease the ability for a surgeon to perform word recall exercises, suggesting music has a detrimental effect on some components of concentration. In addition, ambient music was associated with team members asking for repetition or clarification of verbal communication.** On the other hand, music improves technical tasks performed by experienced surgeons, but may have a detrimental effect on surgeons on training performing novel tasks. Music also had a detrimental effect on monitoring patient vital signs. Anesthesia providers have a more negative view of music compared to the surgical team. One survey found that 25% did not like music, 26% felt music reduced vigilance and impaired communication, and 51% felt it was distracting during anesthetic-related problems.

While music is common in the operating suites and has benefits for the majority of patients and staff members, the data on music in the operating room are worth thinking about to ensure the optimally safe environment for every patient. The anxiolytic and analgesic effects of music are intriguing; therefore, as long as patients agree to music therapy, it is a low-risk and low-cost therapy. However, some patients prefer not to listen to music. It is also important to remember that, although music may enhance the performance of experienced surgeons, some learners have worse surgical performance when music is playing. Therefore, especially in learning institutions, the environment should be optimized to ensure appropriate education and patient care. Also, even though many healthcare team members feel music has a positive effect on team dynamics, many anesthesia providers feel music in the operating room can be distracting. It is clear that before we "press play," we should take a moment to ensure all team members support the playing of music and feel empowered to speak up if communication is impaired or if patient safety is at stake.

## TAKE HOME POINTS

- Music therapy via headphones during procedures can decrease patient anxiety, pain, and sedation needs. The music selected should be within the taste and "listening experience" of the individual patient. We have found, anecdotally, that patients often express a desire to listen to the music that was popular when they were in high school.
- If the patient is going to listen to music via a personal device, figure out how you are going to do this safely and cleanly. Because you definitely aren't going to be able to just pull earplugs out of one patient and hand them to another. For example, at some VA hospitals where the editors have worked, the patients are encouraged to bring an

inexpensive set of earphones with them to the OR and for the PACU. The Nurse Anesthetists maintain personal devices with huge music libraries to then use with the patient's own ear devices. There is no promise that they won't be lost, in fact, the patients are told that they should consider the earpieces to be disposable.

- Overhead music in the procedural suite has been shown to improve the performance of technical tasks by experienced surgeons, but may have a detrimental effect on surgeons in training performing novel tasks.
- Overhead music may interfere with communication among procedural team members.
- Anesthesia providers have a less positive attitude toward overhead music; with many feeling it distracts them from monitoring patients.
- If one member of the operating room team feels the music is too loud, it is too loud! The volume should be decreased, immediately, on the first request. Imagine the medical, ethical, and legal ramifications of trying to explain a decision or adverse outcome because you were distracted or otherwise impacted by the music in the OR or because you didn't turn down the volume of music. You don't ever want to put your patient and yourself in that position.

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# Never Rush Through a Signout

John T. Bryant IV, MD and Ryan J. Fink, MD

As symbolized by the seal of the American Society of Anesthesiologists (ASA), the practice of anesthesia is a profession based on vigilance. Attention to detail and continuous situational awareness are essential to anticipate and avoid preventable complications. Similar to other professions requiring constant vigilance, it is generally accepted that periodic relief of anesthesia providers is necessary to promote patient safety. Extrapolating from data in their landmark 1978 study regarding preventable mishaps in the practice of anesthesia, Cooper et al. found that the provision of periodic breaks to anesthesia personnel during long procedures had a favorable effect on preventing critical incidents by allowing their (earlier) detection by the relieving anesthetist. This finding has not been universal, as some evidence shows that continuity of care throughout the course of an anesthetic case decreases the risk of perioperative morbidity and mortality. **Indeed, a retrospective study by Saager et al. in 2014 showed an 8% increase in hospital morbidity or mortality with each anesthetic handover.** Though examples have been observed of critical incidents attributed to, or perpetuated by, the exchange of personnel, most of these can be avoided by a detailed and inclusive personnel exchange protocol. This chapter presents a stepwise approach to organizing essential data during personnel exchanges to enhance patient care focusing on three critical categories: patient factors, surgical procedure factors, and key elements of the anesthetic plan.

Effective July 1, 2004, all Joint Commission on Accreditation of Healthcare Organizations (JCAHO)–accredited surgical facilities became required to adopt the Universal Protocol to Prevent Wrong Site, Wrong Procedure, and Wrong Person Surgery. This “timeout” protocol provides a point of embarkation in the initiation of a signout protocol between anesthesia providers. Confirming demographic information including age, gender, race, and name establishes the context in which all further information can be understood. Included in the introduction is mention of any medical allergies unique to the patient. Furthermore, it is essential that the replacing anesthetist be versed in what surgical procedure is being performed and its indications in order to anticipate anesthetic needs. Anesthetic technique is dictated not only by surgical

requirements but also largely by co-morbid conditions. Consequently, the next logical piece of information to cover deals with the patient's relevant past medical history. The relieving anesthetist should assume care of the patient only after acquiring a thorough grasp of his or her medical problems, concentrating on cardiovascular, pulmonary, renal, and neurologic status. Attention should be paid to objective measures of physiologic organ system function such as pertinent laboratory values, radiologic studies, and baseline vital signs.

Anticipating and avoiding preventable morbidity hinges on planning around pitfalls inherent to the patient's physiologic state. Knowledge of these co-morbidities helps explain the medications that the patient chronically takes that may compliment or complicate anesthetic management. Discovering that a patient is inadequately treated for a certain medical condition may help to modulate the anesthetic plan and thereby avoid morbidity.

The logic of the anesthetic plan should be apparent after establishing what is being done, to whom it is being done, and what special challenges are presented by the patient. To ensure that critical information is not overlooked, it is useful to conduct the discussion of anesthetic technique in chronologic order. Beginning with induction, it is essential that the replacing anesthetist have a thorough understanding of what technique was used. Critical items to note include the mode (e.g., mask induction, intravenous induction, or rapid sequence induction) and the medications used.

Airway management is the next critical factor to discuss. If a mask airway was utilized during induction, it is important to note the ease of ventilation and the need for airway adjuncts. The relieving anesthesia provider should be informed of the specifics of the definitive airway plan: The device, its size, depth, and ease of placement are all critical factors. If direct laryngoscopy was conducted, the outgoing anesthetist should highlight what kind of blade was utilized and what his or her view was of the glottic inlet.

The relieving anesthetist will need to have an understanding of the type and indication for the monitors that are utilized. If any indicated monitors were omitted, the original anesthetist should be prepared to articulate the reasoning behind the omission. The relieving anesthetist should be aware of the size and location of invasive devices such as venous access lines, arterial lines, and central venous cannulae. It is incumbent on both anesthetists to confirm that all lines are patent so that fluids, blood products, and medications reach the vasculature as intended. Closely related to the issue of invasive devices is a summary of the amount and type of fluids given, estimated blood loss, and urine output up to the point of personnel exchange.

A thoughtful signout should include a summary of important medications administered during the procedure thus far. Important medications to note include

premedications given before induction, as these may later have an effect during emergence. Reviewing the dose and timing of antibiotics given may not only be a cue to administer an overlooked medication but also prompts the relieving anesthetist of the possibility that antibiotics may need to be readministered before the close of a lengthy procedure. The relieving anesthetist will need to be aware of the dose and timing of narcotics and antiemetics, as these also have effects at the time of emergence. Viewed in light of the patient's co-morbidities, the administration of any vasoactive medications is of primary importance. Finally, the use and continued need for neuromuscular junction blockers is critical because they can have significant effects on surgical conditions and emergence.

A final topic of discussion pertaining to the anesthetic plan relates to preparing for the end of the procedure. The relieving anesthetist should know the estimated time and major events remaining in the procedure. He or she will need to continue or modify the existing plan for postoperative pain and nausea. Also, he or she will need to plan for disposition of the patient. Whether the patient will be extubated is a key planning factor. If the patient is to be extubated, does the nature of the surgery require a deep extubation, or do patient-specific factors necessitate an awake extubation? Finally, the relieving anesthetist should understand where the patient is to go following the procedure. If the patient is to be admitted, the relieving anesthetist should ensure that a bed in an appropriate ward or unit has been procured.

After gaining a firm understanding of the patient, the procedure, and the anesthetic plan, it is essential that the relieving anesthetist confirm the presence of emergency medications, equipment, and contacts. Inappropriately labeled syringes have been shown to be a common source of preventable error during exchange of personnel. Such errors have been attributed to the lack of standardization in labels and doses of medications. It is incumbent on the relieving anesthetist to check the identity and concentration of prepared medications and correct any discrepancies. Similarly, the relieving anesthetist will want to confirm the location and functionality of the laryngoscope and accompanying blades. Additional endotracheal tubes of appropriate sizes with stylets should be readily available. If blood products are anticipated to be required, the relieving anesthetist should inquire about their availability. A final essential piece of information is an understanding of who is available for assistance. The relieving anesthetist should not allow his or her predecessor to leave the room without handing down the names and contact numbers for the attending anesthesiologist and anesthesia technician.

Given that the above discussion covered various important aspects of anesthetic care, and that handovers can be quite variable, some practices and centers have implemented standardized checklists to assist in transfers of care. In addition, in 2006

the Joint Commission made "a standardized approach" to handoff a National Patient Safety Goal. Much of the scientific literature about anesthesia handovers has focused on the OR-to-ICU or OR-to-PACU transition, but could potentially be extrapolated to intraoperative handover between anesthesia providers. In general, these studies show an improvement in the quality and reliability of information transfer, as well as satisfaction of the handover process for the involved providers. However, it is not yet known if checklists for anesthesia handovers can improve patient safety. Given anesthesia and surgery practice variability as well as variability in patient populations, each institution would likely need to design, or at least refine, their own handover checklist if it is to be implemented successfully.

## TAKE HOME POINTS

- Vigilance is the hallmark of the practice of anesthesia.
- Periodic short breaks during prolonged procedures can enhance patient safety by giving the anesthetist an opportunity to rest and renew focus. They also afford a new perspective on a case and help to discourage complacency.
- To enhance rather than hinder patient care, exchanges in anesthesia personnel must be accompanied by a thorough and thoughtful signout. Exchanges of information between providers can be highly variable, so consider using a standardized checklist for handovers.
- To promote a thorough, efficient, and retainable exchange, anesthetists should make an effort to give and receive their report free from interruption.
- Other elements that may improve signout effectiveness include using a checklist, taking notes, and having the relieving anesthetist read back information to the outgoing anesthetist to ensure comprehension.
- Any successful signout protocol must include pertinent discussions of the patient, the procedure, and the plan.
- Approaching the signout in a logical manner can assist the anesthetist in assimilating a large body of critical information in an effective, efficient, and safe manner.

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# Don’t Ignore the Folklore—It Can Be a Powerful Ally in Your Clinical Practice

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People may understand statistics, but they believe stories. Imagine you are supervising a junior resident during an eye procedure and the patient exhibits a significant oculocardiac reflex with a heart rate of 17 bpm that is unresponsive to atropine. It is your practice to have a syringe of epinephrine 10 µg/cc available on your cart, and the patient responds to a 2-cc bolus. The next day in a vascular bypass operation, you are supervising another junior resident, and give epinephrine 20 µg to good result for a near “flat line” of the electrocardiogram and arterial line tracings after reperfusion of the lower extremities. The resident (who heard stories about the previous case) asks whether you always have low-dose epinephrine available and, if so, why. You reply that when you were in training, one of your favorite faculty members said to you, “Always be able to get your hands on 20 µg of epinephrine within 2 seconds. You may only need it twice in 5 years, but when you need it, you need that and only that, and you need it fast.”

The stories that we tell, or folklore, can be an indispensable part of our clinical practice. Cultural scientists and sociologists actually recognize several types of folklore; the subset most relevant to the field of anesthesia is known by the scientific term of “institutional memory.” Institutional memory is defined as a collective of facts, concepts, experiences, and plain old-fashioned know-how held by a group of people. It is transmitted (often orally) by senior members of the group to junior members, but just as often it is transmitted through the stories shared among veteran care providers around the water cooler or in the anesthesia break room. Institutional memory can be facilitative to a group’s “way of work,” preserve a desired ideology, or be maladaptive—if too heavily established, it can make change difficult in the face of new information and input to the system.

The value of institutional memory and the importance of lore in maintaining patient safety have been established in anesthetic practice on many levels. Although morbidity and mortality seminars are one type of story, they often leave out an essential narrative

that carries value: the personal experience. Pearls of wisdom that have been developed through folk tales and anesthesia "mythology" can be a source of useful information. In this raw form of folklore, the information distilled through the experience of others is concentrated and often powerful. Telling co-workers a personal story of a specific patient "going south" in a narrative can provide the valuable context that will help that person recognize the diagnosis when they encounter it themselves. (See Chapter 62 for examples of stories about medication errors.)

Stories can have an effect beyond conveying the clinical facts. Stories of an attending thanking the nurse that stopped a procedure when the nurse noticed the attending's breach of sterile practice send a powerful message that patient safety is more important than the caregiver's ego. Stories of the nurse being recognized for excellence by the institution create a folklore about the values of the institution, promulgating the values of the workplace.

Although institutional memory and folklore are frequently based on factual information, almost by definition they are anecdotally based and not outcome based or verified by rigorous trials. The advantages of this are that the information is often vividly presented and therefore quite memorable—the human mind is wired to remember stories, not facts. Judgment is often biased by the "salience" heuristic, in which conspicuous or dramatic events are easily recalled. Use the bias to your advantage: By telling a compelling story, it becomes more likely that the story will be recalled when a person needs to retrieve relevant information. Teaching with the help of concrete examples (our "stories") has been identified as an important and effective teaching strategy. The disadvantages are that anesthesia providers must maintain an open but discerning mind and a healthy skepticism.

Sometimes notions told in folklore can lead to formal scientific investigation. For example, for years, the anecdotal tradition said that anesthetizing redheads was more challenging. In 2004, Liem et al. reported that desflurane requirements to blunt movement in response to noxious electrical stimulation were significantly higher in redheaded women as opposed to dark-haired women. They were able to establish that 9 of 10 redheaded women were either homozygous or compound heterozygotes for mutations on the melanocortin-1 receptor gene. They concluded that red hair appears to be a phenotype linked to increased anesthetic requirement that can also be traced to a specific genotype. It was also subsequently reported that redheaded women have increased sensitivity to thermal pain and manifest reduced subcutaneous lidocaine efficacy. But subsequent studies failed to demonstrate a clinically relevant difference regarding anesthesia requirements—including no difference in the impact of Propofol on BIS—or time to recovery after anesthesia between women with red hair and women with other hair colors. So this oft-repeated story is one that will most likely stay in the

folklore realm and that's okay.

Nonetheless, the value of folklore in the practice of anesthesia and the training of anesthesia providers should not be underestimated. The folklore you hear will depend on where you trained (Table 268.1). Gather as much lore as you can, but remember that although there is frequently at least a kernel of truth, the adage may not apply to all situations. Try to always place it within proper and accepted practice parameters, and use whatever you can to make your practice safer and more consistent.

**Table 268.1 ■ Folklore Maxims in the Practice of Anesthesia**

| Topic | Helpful Folklore |
|---|---|
| **UNDERSTANDING PATIENTS** | • Patients who go to sleep crying, wake up crying.<br>• Dads can cry just as much as moms.<br>• Make your pediatric patients as pristine as possible when wheeling by the parents' waiting room.<br>• Patients are heavily influenced by the prior anesthetic experiences of their friends and family<br>• You might think that you understand what a patient is going through but after you yourself have been through a surgical situation or two, you understand better. |
| **MONITORING** | • If you really want to know what is going on, look at the patient, not the monitor.<br>• If you cannot get the radial artery line, you are almost always too lateral.<br>• Follow urine output avidly—the Foley catheter is not just there to keep the urine off your shoes.<br>• The smaller the patient, the bigger the vigilance has to be.<br>• Never be afraid of the technology. If you can get through all of school and all of training, you can learn the latest monitor. |
| **GOING SOUTH** | • If the acuity of the case starts to escalate, stand up.<br>• In a certain way, as the surgical case gets more acute, the anesthesia case gets simpler until, at |

the bottom of every adult algorithm, are oxygen and epinephrine: code 'em now or code 'em later but also realize that neonates respond to supplemental oxygen by shunting blood flow away from the lungs.

**MANAGING CASES**

- There is a secret to making every case go well—your job is to find the secret and then not let go of it no matter what else is happening in the case.
- It is better to do a difficult case in a happy room than an easy case in an unhappy room.
- Make all parts of the anesthesia case "match" each other and always match the severity of the surgical case.
- Even if circumstances force you to "rush" on an aspect of a case, never rush on the airway.
- Sometimes you have to go "slower" to go "faster." Every procedure has a key step where you need to take your time and get it right.
- Patients will usually be okay if they do all right (meaning that some patients can pull through only if there are no complications).
- If you want train tracks (slang for stable vital signs), give your fluids and narcotics up front.
- Fentanyl is for tubes; morphine is for laryngeal mask airways.
- Try to manage your cases in such a way that the PACU or ICU staff is always happy to see you rolling in the door.
- "What is happening now?" is the most important question you can ask yourself. "What will happen next?" is the bigger most important question.

**PHILOSOPHY**

- You do not work for the surgeon, you work for the patient.
- Do not put anything on the patient that you would not put on yourself.
- The only two drugs that are so good that every patient needs them are oxygen and ondansetron,

and even they have contraindications.
- The reason an anesthesia provider goes to work is to provide access, airway, and precise administration of dangerous drugs—focus your energy and efforts on making these aspects of the case go smoothly.
- Don't forget to smile, unless it would be unkind or uncaring to do so.
- Ever notice how the best of the best anesthesia providers tend to keep quiet about that fact?
- Spend everything you've got in your kindness and consideration banks accounts every day.
- Remember, you too were once a beginner (see above) and eager to make a difference in every case.
- Want a really successful anesthesia career? Remember always that it's about the relationships!

One final note: Here are two pieces of folklore that are so true, they deserve special mention:

- "When you choose your anesthetic, you choose your complications."—Stephen Robinson, MD
- "Never be scared alone; invite all your friends."—Kenneth R. Abbey, MD

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# Don’t Underestimate the Role of Spirituality in Patients’ Perceptions of Disease and Healing, and Remember to Uphold the Right to Self-Determination

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Throughout the years, we have often been asked if the following story is really true. It is indeed a true story. The patient in question was undergoing an extensive head and neck resection for cancer in Room 18 in the old General Operating Room theater at Hopkins and Dr. Cameron (now the Alfred Blalock Distinguished Service Professor of Surgery) was operating just across the hall in Room 16.

Here is what happened that fine morning: Just as a patient was about to be induced for general anesthesia, he waved the mask off his face, and asked to see the Catholic chaplain, as he had just heard God asking him to be blessed before surgery. The priest was paged, but unfortunately was still several miles from the hospital. A considerable delay ensued. As luck would have it, the eminent chief of surgery (Dr. John Cameron) was operating in the next room. His opinion was sought by the surgical residents as to whether the operating room (OR) schedule for that day could tolerate this disruption. Dr. Cameron (to his eternal credit) told the house staff to wait for the chaplain as long as necessary, be thoroughly blessed, and then send the father to his room to bless him and his operation as well on his way out of the operating room suite!

Spirituality and religion can influence many aspects of medical care, ranging from daily activities such as diet and scheduling to major medical decisions such as end-of-life care and abortion. Note that spirituality and religion are related but not synonymous. Spirituality entails a unifying principle of a person’s life, belief in a higher power, and the way a person conducts his/her life in relation to the question of transcendence. It includes the non-physical aspects of a person, such as emotions, personality, and intelligence. Religion, on the other hand, is a set of beliefs, texts, and practices that a community shares in its relationship with the transcendent.

Why should we care about religion and spirituality? First, it is important to patients

and can affect their perspective on disease and healing. Secondly, it has been an area of ongoing research and an area in which more methodologically sound studies are needed. Lastly, it can create disagreements between patients and medical personnel and have ethical and legal implications.

## Importance to Patients

As physicians, we have been trained to focus on the physical aspects of our patients' health, and we continually strive to improve their physical health. However, that is not the only component to our patients' general state of well-being. Multiple surveys have suggested that most patients have a spiritual life that is often equally as important to them as their physical welfare. In a 1998 study of alternative medicine, 35% of patients reported using prayer in relation to health problems. The same study found that 82% of Americans believe in the healing power of prayer. Physicians often fail to consider the patient's spirituality and its relationship to their general sense of well-being. Possible reasons for this failure are a lack of awareness of the importance of spirituality in many patients' lives, discomfort with religious beliefs of others, and the prominence of more scientific concepts in medical education. A patient's spiritual beliefs can affect their interpretation of the disease process and their decisions on treatment.

In a meta-analysis of studies relating to spirituality, religion, and physical health, a correlation was found between patients with a religious/faith affiliation and better health outcomes, greater longevity, and improved coping skills. These patients also had a lower incidence of depression, anxiety, and suicide. Depression has been associated with poorer outcomes in surgical interventions, including cardiac, gynecologic, and orthopedic procedures. These associations cannot firmly establish that religious practice improves surgical outcomes compared to patients who do not practice a religion. Nevertheless, these findings do suggest that a patient's existing beliefs should be recognized and respected.

## The Power of Prayer: Private Versus Intercessory Prayer

There are few studies directly investigating prayer and outcomes in patient populations undergoing surgical interventions. Most of the studies attempting a randomized controlled design are focused on intercessory prayer (IP) for cardiac patients. IP is defined as a request of God, the universe, or some other higher power to intervene on behalf of an individual. Prior to the Study of the Therapeutic Effects of intercessory Prayer (STEP) trial published in 2006, there were four studies investigating IP in cardiac patients. The results were mixed. Two studies revealed a beneficial effect of prayer in coronary care unit (CCU) patients and two (one of CCU patients and the other of patients undergoing cardiac catheterization) showed no difference. The STEP trial

studied approximately 1,800 patients in six U.S. hospitals undergoing coronary artery bypass grafting (CABG) surgery. There were three study groups: the first received prayer after being informed that they may or may not receive prayer, the second did not receive prayer after being informed that they may or may not receive prayer, and the third group received IP after they were informed that they would receive prayer. The study concluded that IP had no effect on error-free recovery, and the certainty of receiving prayer was associated with a higher incidence of complications.

There are limitations to these IP studies. They do not allow for the fact that study patients may also be praying private prayer as well as having close family, friends, and personal religious groups praying for them. Most of the studies do not allow those praying to interact with the patients or follow up with the patient's condition. Also, a contribution to the "power of prayer" may be the patient's own personal beliefs. These studies did not consider the patients' personal thoughts on religion, healing, and prayer.

Even fewer studies have focused on private prayer and outcomes of surgery. One study in 1998 retrospectively studied patients and their use of private prayer as a coping mechanism for the difficulties related to CABG. The results suggested that private prayer might serve to facilitate psychosocial adjustment to the procedure. A more recent study of 246 patients awaiting cardiac surgery suggested private prayer predicted optimism, which implies that clinicians should attempt to provide a better spiritual assessment and care.

## Autonomy, Self-Determination, and Legal Considerations

A difficult situation is encountered when a patient's beliefs and practices conflict with what the clinician would consider as standard medical care, the most notable example in anesthesia practice being a Jehovah's Witness patient's refusal of blood transfusion in the setting of life-threatening hemorrhage. Another clinical scenario in which a conflict between patient's beliefs and medical advice may occur is end-of-life care. A comprehensive review of ethics and legal implications is beyond the scope of this chapter, however, fundamental principles will be discussed.

The general ethical principles that apply to medicine are **beneficence**, **non-maleficence**, **justice**, and **autonomy**. Beneficence and non-maleficence refer to the duty of the physician to provide care that benefits their patients ("to do good") and avoids harm to them ("do no harm"). Justice in this context can refer to the fair distribution of resources in ensuring that medical treatment is offered to those in clinical need. **The most pertinent principle relating to the respect of patients' religious and spiritual beliefs is autonomy, or the right of competent patients to decide what is in their best interest, usually as it relates to consent or refusal of treatment.** Tying into this

respect for autonomy is the concept of informed consent, as patients must understand the risks, alternatives, and ramifications of the decisions that they make. Practitioners must also address concerns that may be the driving force behind a patient's decision to go against medical advice. The documentation of informed consent can protect both the patient and the physician from consequences of respecting patient autonomy. For example, the Jehovah's Witness will be legally protected from receiving blood products against his or her will, and the physician will likely not be held responsible for morbidity or mortality resulting from the avoidance of transfusion in alignment with the patient's wishes.

The concept of autonomy and self-determination has been upheld in courts in various countries, as in the landmark case of Schloendorff v Society of New York Hospital in 1914. This case established the right of any adult with decision-making capacity to refuse medical treatment. However, the involved ethics and legal implications are further complicated in the care of pediatric patients. Parents and guardians give consent for their children based on the assumption that their intentions are to protect the child's welfare. If a physician judges that the child is likely to sustain substantial harm because of religious convictions that interfere with medical care, then the physician may seek legal action to override the parental decision. The first court decision regarding the children of Jehovah's Witnesses was in 1944 and related to violation of child labor laws in the sale of religious literature (Prince v Massachusetts) This case has been cited in medical-legal disputes, as it determined the state's interest in the welfare of children to outweigh the freedom of religious expression and parental authority. In a review of 50 court-mediated disputes between parents and physicians over the care of children, physicians prevailed at the final decision for 40 of the 50 disputes, and were more likely to prevail in religion-based disputes.

## What Can We Do?

It can be argued that the practice of medicine is not only the science of healing, but also an art. In practicing the art of medicine, the physician must be cognizant of the importance of incorporating the patient's emotional well-being into the overall clinical picture and the trajectory of care. Consideration of our patients' autonomy is the essence of providing good customer service, a concept that can be often neglected when practicing the science of medicine. Furthermore, patient satisfaction is becoming an increasingly prominent metric for measuring quality of care in modern medicine. **To embrace the concept of "customer service" is not to indulge the patient's every demand, but it is to uphold our responsibility to listen to our patients and honor requests within reason.** This responsibility becomes particularly important if the request has a possible association with better outcomes. Many patients express their

desire to be prayed over preoperatively by a clergyman of their faith. Accommodating this request may result in delaying the start of surgery. Regardless of the inconvenience that this may impose on the surgical, anesthesiology, and OR staff, the patient's emotional well-being is important, and the patient's comfort level on entering the OR must be considered. This will enhance our ability as anesthesiologists to provide anxiolysis for a patient and to preserve a healthy doctor-patient relationship. Also, should future studies be able to establish a true relationship between the practice of faith and improved perioperative outcomes, the time spent could make a difference in the patient's physical healing.

It is important to note that not all patients fully understand the beliefs of their own denominations regarding particular issues, so pastoral staff care or the patient's own clergy can be helpful to clarify these matters. Also, the patient may not hold the same particular belief as his or her religious denomination, so it is of utmost importance to clarify the patient's wishes, which sometimes requires interviewing apart from family.

Ultimately, patients have a right to be free to practice religion without restraint, regardless of whether those beliefs coincide with those of the physicians and the OR staff. As physicians, we are obligated to respect these rights and make any reasonable accommodations to preserve them.

## TAKE HOME POINTS

- As physicians, we may not always agree with our patient's religious beliefs. Sometimes we may find those beliefs difficult to respect, particularly if that respect could lead to a detrimental physical outcome.
- However, it is well within patients' rights to practice their faith as they choose.
- Previously published studies on religion and health outcomes are controversial and have produced mixed results. Certainly, more studies with improved methods are necessary before definite conclusions are made regarding religion and spirituality and their effects on surgical outcomes.
- Despite this, other studies show that faith and religious affiliation provides some patients with a sense of happiness and comfort that nothing else can provide. Prayer and other alternative healing methods may result in improved outcomes.
- For these reasons, the next time a patient requests a chaplain, faith healer, or wants to participate in a religious ceremony prior to a surgical procedure, provide your patient with that opportunity by not interrupting the spiritual aspect of their healing process (Table 269-1).

**Table 269.1 ■ Major Religions and Issues Relating to Anesthesia and Critical Care**

| Religion | Primary Beliefs | Specific Issue | Teaching |
|---|---|---|---|
| Buddhism | • Accumulation of wisdom to which each generation adds its own understanding<br>• Karma—for every action there is a consequence<br>• Goal is achievement of Nirvana through continual reincarnation<br>• Fate, inn, and ko determine health<br>• Health practices include meditation, chanting, the four requisites, vegetarianism, no alcohol or tobacco, emetics/purging, oils, medicinal herbs, and surgery | Brain death | Not clearly defined without a central moral authority, and although the notion is accepted by some, it is strongly resisted in many Buddhist communities, especially in Japan |
| Hinduism | • Brahman is the supreme being<br>• If prana (life force energy of humans) and chakras (energy centers) are in harmony, good health conditions result<br>• Treatment may focus on balancing "humors" by diet, fasting, purging, enemas, and massage | Autopsies | Hindus believe autopsies disturb the still aware soul that has just separated from the body and should therefore be avoided unless |

| | | | |
|---|---|---|---|
| | | | required by law |
| Islam | • Allah is God and teachings are provided in the Koran<br>• Five pillars of faith include profession of faith, prayer, almsgiving, fasting, and pilgrimage<br>• One main goal is to protect life, and this may contribute to certain healthcare decisions<br>• Illness and death are met with patience, prayer, and meditation<br>• Modesty is practiced, especially among women, and they may prefer female practitioners<br>• Prayer is usually five times daily and must be done facing east | Assisted suicide and euthanasia | Strictly forbidden, although the withholding and withdrawing of life-sustaining treatments is permitted |
| Judaism | • The law of God is set forth in the commandments of the Torah (Old Testament of the Bible)<br>• Saving human life takes precedence over all other laws<br>• The family is the basic unit of society<br>• Spirit and body are separated at death<br>• Sabbath is regarded as the holy day of the week | Ventilator support | Most Orthodox Jews oppose withdrawing but support may be withheld if the patient is very close to death. Reform and Conservative Jews tend to be more liberal |
| Christianity | • One God whose teachings | Blood | Transfusion |

| | | | |
|---|---|---|---|
| | are defined in the Bible (Old and New Testaments)<br>• Salvation is a primary goal<br>• Many different denominations each with slightly differing view points<br>• Prayer used often to ask for healing | transfusion (Jehovah's Witnesses) | violates scriptural ban on "eating blood." Many Jehovah's Witnesses permit purified blood products such as albumin and clotting factors |
| | | Advance directives (Southern Baptist) | Distrustful of living wills: suspect they may be misused to make quality-of-life judgments. Healthcare power of attorney is preferred or an alternative document called a will to live |
| Magicoreligious | • Supernatural forces influence health and illness<br>• Examples include Christian Science and certain Hispanic/African/Caribbean healing practices | | |

| | |
|---|---|
| Holistic | • Forces of nature should be kept in harmony, and these forces dictate health or illness<br>• Examples include Chinese and Native American healing practices<br>• Chinese medicine can include the balance of yin and yang; herbalists and shamans as healers; and the acts of massage, pinching, or cupping<br>• Native Americans may seek a medicine man for folk healing who often leads large communal ceremonies |

This table is not meant to be a comprehensive theological review; rather, it is designed as a quick reference to broaden the healthcare provider's awareness of certain religious practices and possible implications on anesthetic and critical care management. (Adapted from Young C, Koopsen C. Spirituality, Health and Healing: An Integrative Approach. Thorofare, NJ: Slack; 2005;65–69, 80–81; Sulmasy DP. Spirituality, religion, and clinical care. Chest. 2009;135:1634–1642.)

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# What's in a Name?

Charles H. Sandson and F. Jacob Seagull, PhD

Should physicians use their first names? It is a seemingly small, but surprisingly impactful question as anesthesiologists establish and maintain their professional relationships and networks. In complex socio-technical systems where people and technology function together, the performance of the system is the aggregate result of numerous smaller components. The structure of each component impacts the system's functioning. The way that names are used impacts the interactions between the people caring for a patient, the group might follow orders without questioning the established leader, or they might act as a team with input from all parties to optimize care from a variety of viewpoints.

To answer to the question fully, one must understand both the context and the goals of the activity where the names are used. As a teacher to medical students and residents, "Dr." can help create deference to authority, and facilitate learning. To instill confidence in a patient, or to maintain a professional demeanor with a patient, using the title of "Dr." may be a necessity. However, this book is not about "avoiding common professional demeanor problems"; it is about safety and errors. The issue of name and title use is a microcosm of many other safety issues in which efficiency is pitted against safety.

If your goal is efficiency, then using "Dr." may facilitate your goals. The efficiency of an authoritarian system in which directives are not questioned can lead to rapid and precise action. This type of system performance can be essential in a number of situations, such as when there is emergent need for action, or when trying to accomplish a complex task in which only some of the team members possess adequate training or specialized knowledge. A military general who has a strategic vision and access to secret intelligence regarding enemy capabilities relies on the chain of command to execute orders throughout the ranks. In hierarchical systems such as the military, use of titles and formal communication protocols emphasizes and clarifies the formalized structure of the relationship between communicating parties, creating what is known as "power distance." The authority differential is often mirrored by a knowledge or resource differential: the private obeying an order does not need to know the full battle

plan, and will have little insight to offer the general. Information flow is largely "top down."

However, in fluid situations involving multiple parties, each with a domain of expertise and access to specific situational knowledge (a "team"), a formal hierarchical structure can be detrimental to the functioning of the team. In a dynamic situation, information must flow freely between team members, and power distance impedes the flow of information. The direction of flow is not always "top down," as in dynamic situations, the designation of "top" can be dynamic, with different team members being the most qualified to lead as a situation evolves to make different expertise most relevant. A scrub nurse may have the best perspective on breaches of the sterile field, the anesthetist the best understanding of the current patient physiology, the surgeon the definitive knowledge of the next surgical step and when it will be initiated. Teams that seek this situational expertise perform better: better outcomes and fewer adverse events. This "deference to expertise" is a characteristic of systems that function with high reliability in the face of dangerous and uncertain circumstances.

So in considering whether to be "Dr. Smith" or "John" to the members of your care team, ask yourself whether you would want to know about what your team members see to keep abreast of any evolving situations. If you want to catch a potential adverse event early, reducing power distance will increase the likelihood that you will hear about an issue before it becomes a big problem. There is increasing evidence to support the positive effects of reduced power distance.

From the perspective of patient safety, evidence supports the shift to decreased power distance to improve safety. This approach is reflected in the aviation practice of "Cockpit/Crew/Crisis Resource Management" (CRM), and also in research on how high-reliability organizations function. Using first names instead of titles can help achieve the goal of improved safety—both during the active work, and in the reporting of ongoing problems. The use of first names supports a culture of safety, which can improve outcomes.

We would strongly endorse using first names among caregivers. Doing so may require a shift in institutional culture to achieve, but it is worth it. It is better for teams, better for safety, and ultimately better for patients.

## TAKE HOME POINTS

- Variation: There is a wide variety of preference on whether physicians use their first names, dependent on context, goals of communication, and culture.
- **Advantage of using "Doctor":** The use of the title "Doctor" helps patients identify and trust the expertise and qualifications of the care giver, and maintains

professionalism. The authority that the title supports can be useful when directing emergent situations where speed and efficiency is paramount.

- **Advantage of using first names:** The use of first names decreases power distance and increases collaboration. It is better for team function in dynamic situations, reducing the likelihood of adverse events and improving patient safety.

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# We Are Not the Only People Who Care About the Patients

Brian T. Gierl, MD, Sara Lyons, MSN RN CNOR, and F. Jacob Seagull, PhD

> "Perception is reality. If you are perceived to be something, you might as well be it because that's the truth in people's minds."
>
> –Steve Young

The anesthesia provider is a valuable member of the patient care team and is reliant upon a number of people to support them while they provide routine or emergent care. Nurses—including the preop nurses, the operating room (OR) nurses, the postanesthesia care unit (PACU) nurses, and the ICU nurses—form much of that care team and the quality of their care can sometimes be influenced by their enthusiasm for their job. This in turn is heavily influenced by their work environment, including their perception of the surgeon and anesthesia provider. Below are a collection of quotes that various perioperative nurses contributed for this chapter in response to the question, "what would you tell an anesthesia care provider if you could tell them anything at all." You might be surprised by the large effect that seemingly small things you do have on nurses' lives.

## From the Preoperative Evaluation Center Nurse-Practitioners

**"Please don't delay in calling us back. If we call you about an issue with an upcoming patient, it's going to be about something important and unusual and something you need know."**

In our thousands of years of cumulative practice, we have seen the nurse-practitioners (and also physician-assistants), who are doing the primary anesthesia preoperative evaluations find and resolve some amazing patient safety issues, including undiagnosed and severe aortic stenosis, rare blood types, a true family history of malignant

hyperthermia, really important anatomic variations, and so forth. These professionals are very good at what they do and they do it full time. They won't be calling you for anything routine. If they call with a question, for advice, or for you to come and see a patient, you should do everything you can to address that call.

## From the OR Nurses

**"Just introduce yourself."**

- It reinforces that we are all part of the team and that we should contact you with our patient concerns. It is not just a part of the mandated "timeout" procedure, it's also a great idea.

**"Your mother does not work here."**

- The used endotracheal tube, syringes, monitors, and so on, should not regularly be strewn about the OR at the end of the case.

**"Please don't ask us to be your secretary or personal assistant."**

- I have things to do. If you forget to bring the patient's chart back to the OR, it isn't anyone's job to go and grab it … so you should at least ask nicely.
- We don't want to deliver your bad news, so please place your own calls to the surgeons, scheduling desk, and the like.
- Above all, don't attempt to triangulate us in disputes and disagreements with the surgeons. We are not on your side or on their side—we are on the patient's side!

## FROM the PACU Nurses

**"TMI comes out way too often."**

- Don't have personal phone calls while you're watching a patient recover in the PACU. It isn't eavesdropping when you're standing next to me. I can't tell you how much I know about the staff based on the personal phone conversations that they have in the middle of our busy PACU.

**"We don't call you just to chat."**

- Realize that we call with questions and orders that pertain to the myriad of forms that we are required to complete in order to move a patient either into the OR or out of the PACU to the next stage of recovery. We didn't make the forms. I chose to be a conscientious provider, and I think that you want me to be a conscientious provider.
- I ask a lot of questions when I'm not familiar with my patient's illness, medications,

or procedure. It ultimately helps our team provide better care.

**"You might have a medical license but you're not licensed to be abrupt or rude."**

- Yes, you have more training than we do and with that training comes more responsibility and more stress. However, that medical license doesn't give you an excuse to have a bad attitude.
- We chose this job to help people, not to be degraded. Remember, that you're salary is 10× what the average PACU staff member is being paid. And we're all working for the same goal.

**"Don't just ditch us with your patient."**

- We need signout to understand your patient's issues and to provide good care. You are the only one who knows that information when the patient gets to the PACU. Share it!
- If the pulseox won't pick-up, you shouldn't pick-up and leave unless that patient is doing calculus.
- I need ins and outs and patient disposition—i.e., admit or send home. You know that I'm going to ask, so you should have an answer.

## TAKE HOME POINTS

- It seems almost too obvious to state, but permit us—the nurses are highly trained and dedicated licensed professionals who take their responsibilities as patient advocates just as seriously as we do. Their problems are the patient's problems and therefore yours as well.
- More than one physician has assumed they can make a longitudinally successful career while eschewing the goodwill of the nursing staff. In today's world, you can't. We are all on the same team.
- Use every last bit of your professional energy and the good manners that your mother taught you to work toward a polite and productive relationship with the perioperative nurses. This includes courteous cooperation that goes both ways. It's not for the sake of being courteous, it's for the sake of quality care for the patient.

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# Working in the OR—Sometimes the Staff Gets Sick or Injured, Too

Raymond G. Graber, MD

Here you are, coming to work, ready to do your part to be a healer and deliver a positive experience for your patients. Did it ever cross your mind that you could be one step away from being the patient instead? The hospital is a microcosm of the outside world. We are hardworking, dedicated, exhausted, pigheaded, and sometimes we get sick or injured, too.

## Workplace Injuries

One Friday afternoon, I was walking down the OR corridor—not rushing, but moving with my usual pace. (OK, those who know me will tell you I am a speed walker!) I didn't notice that slick spot on the floor not too far from the scrub sink—where a soapy puddle had just been wet mopped. My left foot hit that spot, and shot forward, and as a result, I came down with all my weight directly on top of my right knee. It was immediately painful, but I was able to get up and hobble away. A partner took pity on me, and relieved me from my ongoing case. I iced the knee and Ace wrapped it. An orthopedic resident told me it was probably just bruised. However, on the following Monday, I was back at work, still super sore. One of my orthopedic buddies arranged for an x-ray. The film demonstrated a patella fracture—nondisplaced—more of a hairline crack. No surgery was needed, but I had to take time off, and wore a knee immobilizer for a period of time while I was healing up. I was lucky. Soon after, one of our cardiac team perfusionists had a similar but worse injury. She was rushing around setting her pump up for an emergency cardiac case. She tripped over the electrical wires, landed on her knee, and wound up with a much more complex patella fracture. She needed two surgeries to get her patella fixed, get mobile, and get back to work.

**Comments**: We tend to think about needlestick injuries as the type of trauma we are most likely to see in the operating room. However, it is a fast-paced environment, with floors littered with empty wet plastic IV fluid and blood product bags, and lubricated

with irrigation and IV fluids, soaps, prep solutions, the slippery stuff sprayed on scopes, etc. **Propofol can be especially slick on the ground.** There are also tons of electrical wires and cables all over the place, just waiting for the chance to ensnare you. If you see a wet spot, throw a blanket on top of it to soak it up. Collect all your loose bags onto a dry OR towel, so someone hurrying into the room with the vials of calcium chloride that you requested doesn't slip on them (while pregnant!), as happened to another one of my colleagues. Try to keep wires out of your way, tape them to the ground, or cover them over with a blanket. Be aware of your environment! Be aware of the phenomenon of inattentional blindness—a person in a hectic and intense environment with expected stimuli or distractions that must be attended to (and what is an OR, if not that?) is at risk for failing to see something in plain sight because the human limits of differential perception, recognition, and action are exceeded. Remember that classic scenario where the person in the gorilla suit walks through the circle of people bouncing balls and nobody watching the video sees it? The same thing happens in the OR environment.

There are a multitude of other workplace-related injuries and risks that can occur in the operating room. Musculoskeletal issues include carpal tunnel syndrome (related to airway management?) and low back pain related to patient moving and lifting. We have an epidemic of obesity in our patients. Make sure you are using rollers and sliders and lifters and have adequate personnel to prevent injury to the patients and the OR staff. Luckily, we don't use highly explosive anesthetic gases anymore, but there are occasional case reports of anesthesia machines that explode for different reasons. OR fires are an ongoing issue. OR personnel are also exposed to anesthetic gases and radiation.

## Working Sick

People also get sick in the OR. I know of another story … (Okay, it's about me again!) I was working labor and delivery one Friday night, and sometime about 2:00 AM, I started developing crampy, generalized abdominal pain. I was able to finish my shift, thinking I was coming down with a stomach flu. I went home, and generally didn't feel good for a few days. No fever or specific point tenderness. On Monday morning, I was feeling a little better, and went back to work, where I was assigned a CABG. During induction and line placement, I started having chills, then rigors. I notified the Anesthesia Coordinator. I was told they would work to relieve me, but it would take a little while. I got the patient on pump, got relieved, then paged a GI Doc friend at the hospital. He immediately saw me, worked me up, and before I knew it, I was admitted to the hospital with a diagnosis of a ruptured appendix and a pelvic abscess. I soon knew the joys of percutaneous drainage, IV antibiotics, ileus, and surgery.

**Comments:** People come to work sick—especially physicians. They feel under pressure not to cancel on their patients, and they are under pressure from their administrators to produce. Or they are in denial—like I was. Keep an eye out for these people. Try to get them home to rest or help them get the care they need. The editors have been known to plop an ill colleague down in the Anesthesia Office and start a badly needed IV, and more than once, too.

## Heads and Hearts

When I was a junior faculty member, one of my senior partners, a very well-respected cardiac anesthesiologist, developed expressive aphasia and dizziness during the middle of a cardiac case. The nurses in the room recognized something odd going on, and called for assistance. He was taken to the emergency room, worked up, and found to have a large cerebral aneurysm. He underwent surgery, but unfortunately had a stormy course, and was not able to ever return to work.

I was recently working the night shift, running the evening operating room schedule. I was stat paged to a room where an appendectomy was underway. The attending surgeon had gotten dizzy, and was sitting down. On quick evaluation, it was obvious he had developed weakness on one side, facial droop, and aphasia. He was having a stroke. We put him on a cart, took him to the recovery room, and paged the "brain attack" team —our hospital's rapid response team for possible strokes. He was quickly evaluated and treatment was initiated. In the meantime, we located another general surgeon to finish the case.

A surgeon was performing a series of relatively short ambulatory knee scopes. He developed chest pressure and SOB. He was given an aspirin, and the cardiac rapid response team was summoned, and he was whisked away to the cardiac cath lab, where he was found to have a tight lesion. A cardiac stent was placed.

I was working late, and noticed a colleague standing by our OR desk, and he didn't look right. He had just walked up two flights of stairs, and was feeling acutely winded and dizzy. I grabbed one of my ICU colleagues, who happened to be walking by. We took our partner to the recovery room, put him on a stretcher, and put monitors on him. His cardiac monitor showed a supraventricular tachycardia. We placed an IV, and administered one dose of adenosine—and converted him back to normal sinus rhythm.

**Comments:** Those of us who work in the OR have risk factors for cardiac and cerebrovascular diseases just like anyone else. Sooner or later, you will see risk factors transition and become actual events. Know how to get the right expeditious help when the time comes.

## Syncopal Episodes

When I was 20 years old, having just finished my freshman year of college, I got a summer job as a surgical technician. On my first day, my job was to observe and get acclimated to the environment. One of the first cases that I watched was an exploratory laparotomy. I remember a large abdominal incision, with all kinds of bowel spilling out. I was soon backed up against the wall, turning green. A kindly nurse took me out in the hallway to catch my breath. I think about this when I see observers in the OR. We have all kinds of student observers in the OR–-including high school, college, and nursing school students. Occasionally, one of them will begin to get wobbly. Hopefully, they don't fall face first in the surgical field, or straight back onto their noggin, but instead get assisted into a chair.

**Comments:** Everyone, once in a while, will have individuals who are needle shy, and suffer syncopal episodes during IV starts. It frequently seems to be the young, strong, body builder types. If you work in a VA hospital, sometimes it is the most fit Marine. You easily place a routine IV, look up at the patient to tell him all is well, and notice that the patient is sweaty, dizzy, and the eyes are rolling back. OK, no big deal, you lay him flat, put them on the monitor, and see what the patient needs. On the other hand, we have also seen family members go down—they can vasovagal in response to seeing blood or a family member getting an IV. We have had at least one episode where a family member fell back and smacked her head on the floor. She was taken to the emergency department, and got diagnosed with a concussion. I have also had "two for the price of one." I was placing an IV in a man—and noticed that the wife had gotten dizzy, and slumped to the floor. (Luckily, she had been leaning against a wall, and kind of slid down it.) In response, the husband's eyes rolled back, and he passed out too. Nowadays, we try to get our IVs in as much as possible before we let family come to bedside.

## Expect the Unexpected

We had a surgeon who had a very annoyed chronic pain patient in his office. So annoyed, the patient pulled a gun on him. There was wrestling over the weapon, and in the process, the surgeon was shot in the abdomen. He still managed to wrestle the gun away, and subdue the other guy. He was rushed to the OR, and patched up. The OR staff who worked on him not only had to deal with an emergent X-Lap and a bleeding patient, but also deal with the fact that it was a colleague that they all knew well and liked. It's always a little different when you are taking care of someone you personally know.

I had an old mentor, who loved to tell stories. He used to tell a story about the time

he and a CRNA responded to a code in the basement of the local VA hospital. When they arrived, they found an active gun battle, with a man down. So someone called a code. They had an exchange something like this–-"Ok–-you go intubate that guy" followed by "No way-– your turn!"

**Comments:** We live in a violent society. Do not make the mistake of thinking that serious violence can't or won't or hasn't happened in your hospital. You are not obligated to enter a patient interaction if you fear bodily harm. **Know how to get security to your area if needed**.

## Conclusions

We are not invulnerable. We get accustomed to our high-stress environment, and even take pride in it. It is easy to forget the effect it can have on a newcomer. It is easy to forget the consequences of stress on our lives. We have the job of being vigilant and watching over our patients—but keep an eye open on family and staff, too. **Let's be safe out there.**

### TAKE HOME POINTS

- Workplace injuries include falls, back injuries, needlestick injuries, carpal tunnel syndrome, etc. Be aware of your environment, and take steps to lessen risks.
- Keep an eye on visitors and family members. They can have syncopal episodes and falls, too.
- Operating room doctors and nurses may come to work sick, or may get ill while working. Watch out for them, get them home, or help get them the care they need.

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# The Physician as Patient—What I Learned During the Last Five Times I Went to the OR on the Stretcher Instead of Pushing It

Catherine Marcucci, MD

I've been a trauma patient twice in my life. In both instances, one day I was in the operating room doing cases or otherwise doing my daily schedule and the next day I was literally down for the count—in the ICU or on bedrest or both—for a period of months. The acute phase of both of these unfortunate episodes involved going to the operating room pretty urgently—once at midnight for emergency debridement of necrotizing fasciitis and once as an urgent add-on case to repair an open trimalleolar fracture. And then I had a total of three follow-up surgeries to deal with the later sequelae of these fun little walks in the park. I'm fine now.

But I sure learned a lot from being a patient on these medical odysseys and, truly, the most important thing I learned is how grateful I was to receive really excellent anesthesia care. And how important all the tiny details of our specialty matter to the patient. I felt as if the universe was paying me back for trying my feeble best all these years to deliver meticulous and kind care. I bet the same is true for every other physician who goes to the operating room.

What else did I learn?

) The anesthesia care was the highest level of care in the hospital. The surgeons were competent and nice, the ER staff was the same and I believe followed their protocols accurately, and the floor and ICU nurses were compassionate. But the anesthesia care was the best of all the services. We tend to think that we are invisible to the patients and this may be true in terms of patients not recalling our names a week (or even hours) later. But the effects of exemplary anesthesia are not invisible—and made a significant difference in my perioperative course, several times. On the day after surgery to repair my ankle my husband said to me, "I see the cast and the IV, but I must say you seem pretty clear mentally, are eating, and don't look like you are in much pain." I had the most beautiful blocks done for postoperative pain (thanks, Glen!). Because I wasn't in significant pain and I wasn't vomiting, I started doing isometric

arm and leg exercises and mobility exercises the very next day.

) I was very worried about being a "bad patient" for my friends and colleagues. I really wasn't concerned about them doing a bad job for me; I was concerned about me doing a bad job for them. So don't fret if it takes two tries to get the IV in. Your patient is busy feeling guilty for not having easier veins.

) **Chat but don't joke to your physician colleague.** Do not say, "It figures!" if you need a do-over for something and then mention that you never have problems with lines or spinal anesthetics or whatever it is. I really never realized before I was laid out on a trauma stretcher, how much emotional energy humor and jokes take. Of which I had exactly none in reserve, so even responding to a joke would have felt like a burden. And this goes both ways. An associate of mine who was undergoing an elective surgery jokingly told the anesthesiology resident in preop that "since I'm an anesthesiologist, I probably have malignant hyperthermia or pseudocholinesterase deficiency… or both." As you might imagine, this resulted in a serious in-depth analysis of his past anesthetic history.

) Because I was significantly but not desperately and morbidly unwell, I welcomed chatting and even hearing a bit of the news around town from the local and national anesthesia communities. It helped to pass the time so I wasn't lying there in a shocked state, looking around and thinking, "why am I on this stretcher when I should be up working?" This was true even for my later elective surgeries.

) My anesthesiologists treated the physician-as-patient and loss-of-power issues warmly and briefly, right at the start of their care of me and then didn't mention it again. They did not keep saying, "but of course, you already know that." That would have also been repetitious and difficult for me, to muster the energy to mentally keep going back and forth from provider to receiver of care.

) But use your own personality to ameliorate your patient's loss of power. And, if you are comfortable divulging the information, don't be shy about mining your own past. Because, I must admit, it was helpful for me to hear about when my anesthesiologists themselves were in this most freaky role reversal. So, for example, you can say, "On a scale of 1 to 10, how are you doing with not being the person with the propofol? I had knee arthroscopy last year and I'd say I personally was about a 4 or 5." This gentle and affiliative approach, that is, referring to details of your patient's practice without asking or forcing them to make their own medical decisions is the right one, I think. I got through easiest when I could in a small way retain my identity as an anesthesiologist while not having to act as my own anesthesia provider and decision maker. This approach is also easy to amend for other specialties. For example, "Gosh, last week you read ECGs and next week you will be reading ECGs again, but today your name is on the OR schedule. It's weird, isn't it? I broke my foot 4 years ago skiing and needed pins and I remember thinking, why the heck is my name on the OR board?"

') Here's how my anesthesia care givers presented their specific anesthesia plans: They didn't let me pick the anesthetic and drugs and they also didn't just inform me what I was going to get. Instead, they told me what they usually did and wanted to do for my case. They also dished up a bit of discussion as to how their practice had evolved along these lines. And they politely paused and gave me a chance to comment and even, in two instances, asked me about my own practice. And then they gently and quickly proceeded to do exactly what they had described. Without joking. **They did not follow the clichéd and not very helpful maxim that instructs us to "treat our physician patients like any other patients**." Because, of course, you don't usually discuss with your "regular" patients how you arrived at doing this type of anesthesia for this particular procedure for this particular surgeon. Or show them their intraoperative anesthesia records.

') Everything you routinely say to patients is true. Really true. The operating room is freezing, the table is very narrow, and there is a big rush of noise and activity. It's uncomfortable and disorienting. And you don't see very much of what is going around you, so what the anesthesiologist is saying and describing becomes very important. You may also feel (as I did) that there is a limited supply of gas flow through the mask even though the oxygen is running at >10 LPM and the pop-off valve is open and you know you are oxygenating and eliminating $CO_2$ just fine. Even though I have coached thousands of patients at induction that the circuit is a lot like a scuba mask, I still benefited from hearing exactly that.

') Early in my training, I had some clinical mentors who insisted on a quiet and calm room for induction and I now understand why. And whole-heartedly agree. I have also seen some very skillful clinicians tailor in-the-room music to the patient's preference and I would recommend that as well, if possible.

0) **Ketamine hallucinations are not pleasant.** It's not just a question of "vivid dreaming"—they were terrifying. Plus, both times I received ketamine administered by nonanesthesiologists, I did not receive any benzodiazepine. If I had not known what was going on, I would definitely have thought I was on my way to dying.

1) Noise in the immediate postoperative period and PACU was at least as much a problem as noise in the preoperative period. It's significantly distressing. One of my anesthesiologists did a really cool thing. She came and spoke quietly right in my ear and told me that my case had been "completely benign" and she would be back later to show me my chart. Which she did and which I was happy to glance over.

2) Make as much contact as you can in the postoperative period with your physician patients. I had extra postoperative visits of a "social" nature, which I very much appreciated and would recommend. Ask them what advice you have on being a physician patient. Ask them what the ketamine was like. Or chat about the OR schedule for the week coming up or any little subject that will help them to reconnect to what they see as their most true and rightful role in the health care system.

3) Reassure your physician patients that they did as good a job in the care-receiver role as they try to do in their provider role. This might seem hokey and awkward, but it meant a lot to me.

## TAKE HOME POINTS

- Your anesthesiologist and physician patients deserve just as much empathy and empowerment as any other patient.
- There's a significant probability that your patient is feeling shocked and nervous about the role reversal and loss of power. Good patient-centered care for physicians takes this into account.
- Set aside the old maxim that you are going to treat your physician patient exactly like any other patient. You're not. You might not take significantly different actions in terms of your basic anesthetic plan but what you say to your patient will be more and different. You may call them the night before an elective case to say hello and ask how they are doing. You may pay some social calls in the postoperative period. And this extra and insider communication is okay and even desirable if it helps your patients stay connected with their identity as a caregiver rather than a care receiver.
- Don't joke! If you need to start another IV, just matter-of-factly say, "This IV isn't running well. I'm going to start another in your left hand." Period.
- Exemplary care of our patients is its own reward. But sometimes, when you take care to fill up the goodwill basket, the universe gets it back to you in your own hour of need.

## Suggested Readings

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# A Primer on Simulation in Anesthesiology—Definitions and Concepts

Brian T. Gierl, MD, F. Jacob Seagull, PhD, and Jeffrey R. Kirsch, MD FASA

## Fail in (simulator) training so you can succeed in practice!

We are strong proponents of simulation and the use of simulator training in anesthesia training and evaluations. We are fortunate to have extensive experience in the field and one of us (JRK) has also had the opportunity to write the requirements for the Anesthesiology RRC for simulation. We believe it is a great tool to help practitioners become better communicators and also to reflect on their practices.

We are happy to note that the discipline of anesthesia was one of the first adopters of this philosophy, opting to apply simulation in medicine. Anesthesiology now successfully employs simulation as a part of the American Board of Anesthesiology's (ABA) Objective Structured Clinical Examination (OSCE) and continued licensing via the ABA's Maintenance of Certification in Anesthesiology (MOCA). They are successful because both OSCE and MOCA simulations are the result of extensive planning and careful design.

However, despite its early adoption by our specialty, attempts at anesthesia simulation still can fall prey to some common pitfalls. That is, without proper planning to define clear educational goals before the simulation, as well as appropriate and qualified debriefing to digest the knowledge, the learner in a simulation may only leave with a recollection of having seen a highly engineered mannequin. This chapter will give you a background on the basic principles that are necessary to design a high-quality simulation.

To start, if you plan to create a realistic anesthesia case similar to what you have experienced, leaving the learning objectives to be determined retrospectively, your simulation is less likely to result in meaningful learning. Instead, scenarios should be designed to meet predetermined goals—for example, to identify the signs and treat malignant hyperthermia. Goals can be based on skills needed for common events (to learn fundamental skills), or skills critical for uncommon, high-morbidity and mortality

scenarios where an appropriate response can save a life. Scenario goals can also be generated to avoid recurrence of actual failures leading to a sentinel event. Often, teamwork and communication are significant contributors to a bad outcome—both of which can be improved through simulation training. Principles of teamwork and communication can be trained in simulation to help teams gain skills and familiarity handling similar situations in the future.

The details and progression of a scenario should be tailored to meet appropriate learning objectives for the target audience—either a single individual or the team members that will be involved in the scenario. Keep in mind that bringing in more team members can add to scenario cost and their availabilities can impact scheduling as well. Goals should be written for all attendees—do not have a circulating nurse or nursing student present for the scenario without any learning objectives for him/her unless he/she is a confederate who is present to execute the scenario. **You won't be team building if you make some members of the team inconsequential.**

Cognitive Load Theory (CLT) is an important concept in simulation design and the cognitive comprises two forms of load. Intrinsic load is the pertinent medical information that the learner or team must seek, identify, and process. Extrinsic load is the extraneous information—distracting information that is not relevant to the patient's pathology and the chatter in the OR theater. Simulation is designed to provide an adequate cognitive load in order to simulate a real-world situation. However, too much cognitive load leads to cognitive overload and will diminish performance and learning because the learner is too distracted. **There are three dimensions of cognitive load—fidelity, complexity, and autonomy or degree of support.** These should be tailored to the participant. It should be noted that "fidelity" in simulation may not require complexity or high technology (see Hamstra et al., for important discussion of the concept). Minimize extrinsic load for a novice learner. A simple airway model (low complexity) without any vital signs (external load) while supervised (support) would be appropriate for a first attempt at intubation. For advanced learners, it might be appropriate to have them try and intubate a mannequin (high fidelity) with a difficult airway (high complexity) with a simulated hemorrhage (high external cognitive load), unaided (no support). Some of the extrinsic factors, such as the noise of a simulated trauma bay for a trauma resuscitation, can be an inherent task characteristic necessary for accurate simulation.

- Fidelity—Refers to how realistic or accurate the simulated experience is for the learner. It consists of three dimensions:
  - Physical fidelity—Is the simulation environment appropriate? Do the embedded participants act as they would in a clinical scenario? Is the "orthopedic surgeon" using a real hammer?

- Conceptual fidelity—Do the mannequin's vital signs, $EtCO_2$, etc. match the clinical scenario?
- Psychological fidelity—Are distractions such as the usual OR chatter present? Are the ever-present time pressures also simulated?

- Complexity—From the Latin roots meaning "woven together," complexity refers to the extent that the different elements of a simulation interact with one another. A stand-alone intravenous cannulation task trainer would be of low complexity.

- Autonomy—Is there an assistant to help prepare the patient and/or the equipment, or is the operator expected to prepare those areas as well?

Templates for scenario design are available for download from the Internet. One popular and freely available version is the "Modified Duke Template" available from the University of California at Irvine, along with an excellent companion guide to assist with simulation design. http://sites.uci.edu/medsim/education/scenario-development/.

A scenario should be designed in accordance with learning theory, which suggests that learning is influenced by cognitive factors, behavioral factors, and environmental factors. The more factors that we can engage as educators, the more successful the learning may be. For example, when a learner reads a textbook, he/she only interacts with content; a lecture adds interaction with an educator; and a learning discussion adds interactions with other learners. In simulation, the learner interacts with the educator, the other learners, the content, and the simulation environment. These interactions should be planned to engage the experiential learning that develops critical thinking, problem solving, and decision-making skills that make simulation a higher form of learning.

Debriefing, it can be argued, may be the most important part of a simulation. Beyond simply reviewing and grading the scenario, it is a chance to consolidate and crystalize the lessons learned into long-term memory. A video recording of the scenario can be very helpful, as learners often neither remember their own actions, nor appreciate the implications of their actions. It may also be important to address the emotions that learners may have experienced during the case, provided, this is done by educators who are sufficiently qualified, knowledgeable, and experienced to do so. Failing to address emotional responses can lead to panic in future simulations or worse, in future real-world scenarios. The act of debriefing allows for reflective observation that acknowledges both the technical and emotional aspects of the completed simulation, then progresses to an active discussion to conceptualize the thought patterns that were applied as well as further thought experimentation as to what could have been done differently and what should be done in the future.

We also feel strongly that it is incumbent on the anesthesia provider to stay current

with advances in simulation teaching and science. It is already a huge field with many opportunities for further research and applications. It is incontrovertible that the application and scope of simulation in anesthesiology will continue to broaden led, we believe, by the academic centers. Our institutions all have simulation labs that are busy, getting busier, and continuing to evolve. For example, at Oregon Health and Science University (OHSU) we operate an ASA-approved Simulator Center. **Our simulator courses are somewhat expensive as faculty are compensated but, overall, we operate on a nonprofit basis.** The cost is worth it to us and our students as we have found that after simulation training, our residents and faculty absolutely feel more confident providing care in difficult situations. Over the years at OHSU, we have also run a simulation program for the code response teams. We feel this has resulted in much-improved care during these very challenging situations. We toss it out as an additional thought experiment that, if money were no object, it would be interesting to evaluate what would happen if all faculty members undertook "refresher" simulation training several times per year and if prospective faculty were given simulator opportunities as part of their application process.

In summary, we want our readers to appreciate that starting with planning a scenario to meet specific goals, to designing a simulation for specific learning objectives, to debriefing the learners once they have experienced the scenario, there are many opportunities to apply simulation effectively to avoid anesthesia errors in the real world.

And finally remember always, whether in the real world or in the simulation lab,

Failing to plan is planning to fail.*

—Benjamin Franklin.

## TAKE HOME POINTS

- Our specialty was an early adoption of simulator training for practitioners at both beginning and more advanced levels of expertise, which makes complete sense considering who we are, what we do, how we approach that, and our early adoption and promulgation of other landmark patient-safety initiatives.
- The ABA now utilizes simulation as a formal component in its certification exams and processes.
- Simulation is powerful but not a fail-safe preventative remedy for everything that can go wrong in clinical anesthesia practice. It is most successively and appropriately employed to meet predetermined goals pertaining to selected clinical situations.
- The outline, details, and progression of a clinical scenario should be clearly

planned, written, and appropriately tailored for each person in the scenario.

- Cognitive load comprises intrinsic and extrinsic load. Intrinsic load is the pertinent medical information that the learner or team must seek, identify, and process. Extrinsic load is the extraneous information—distracting information that is not relevant to the patient's pathology and the chatter in the OR theater.
- Fidelity is how realistic the experience is for the learner. It has physical, conceptual, and psychological components.
- Complexity is the extent that the different elements of a simulation interact with one another.
- Autonomy is the degree of independence under which the learner is operating.
- Debriefing, if done well, may be one of the most crucial and valuable parts of the simulator and learning experiences.

## Suggested Readings


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*We are big fans of Dr. Franklin! Please see the last entry in the book; it's an entire chapter of Ben Franklin quotes applied to the field of anesthesiology.

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# What Makes a Great Anesthesia Resident?

Staci Allen, DO and Raymond G. Graber, MD

Collectively, the authors of this book have trained thousands of residents. Since this book is about the spoken tradition, we thought we would take just a bit of space and time to tell our junior colleagues straight out what we are looking for. We have ruefully discussed among ourselves that we could have benefitted from hearing this, plain and simple, during our own training years. And a quick word before we start in with our advice—this chapter isn't about the quantitative measurements of resident performance. There are myriad metrics that are used to track progression in the simulation lab and from CA-1 to CA-2 to CA-3 and on the in-service examinations and these have been studied and debated in some depth. Rather, what we are hoping to share is an approach to developing an "emotional quotient or EQ" that will carry you through these fun, challenging, and sometimes frustrating years.

When an anesthesia trainee hears how many attendees there were at that year's ASA meeting, there is the tendency to think that the anesthesia community is huge, but it isn't. Building your network starts from your first day of training, not your first day after training. And it's so important to grow it carefully and tenderly—you will rely on these professional relationships and your reputation for your entire career. One of us once stopped in a room on the way out the door in the evening to make sure the oromaxillofacial (OMF) resident down in Room 14 was okay and had had a break. He was okay but hadn't had a break and ducked out. A small event of only 10 minutes that was forgotten until it came up in a job interview, at a different instituion, 9 years later - when the OMF guy was interviewing the anesthesiologist's sister!

So, without further ado, please use the following information and advice in the spirit in which it is given. First, we have the attending viewpoint, which was solicited from this book's editors and authors. Then, we have the viewpoint of a current fellow, to get the view from the other side—your coresidents.

## The Attending Viewpoint—What Makes a Great Anesthesia Resident?

When we start to think about qualities that make for a successful resident, some of the following things come to mind: **mature, responsible, reliable, dependable, dutiful, diligent, energetic, enthusiastic, adaptable, curious, imaginative, and insightful**. Let's expand on some of these …

**Emotional maturity and appropriate expectations:** A trainee will make mistakes —blown IVs, esophageal intubations, having zero twitches at the end of the case … We have seen these all before. A resident should be able to admit that they made an error, lest their supervisors lose confidence in them and suspect they might try to hide something and hope that no one notices. Residents should also realize that they need to accept their fallibility and learn from their mistakes, but not repeat the same mistakes. Always strive to improve your practice. Know when to be hard on yourself, but don't be too hard on yourself.

**Communication:** Call, page, or email your attending to discuss difficult patients and complicated cases the day or night before. During cases, keep your attending informed of case progress and issues that arise. Start each call from the OR with where you are and whether the patient is stable—a call from a trainee could be anything, and we want to know if there is an emergent issue. Part of being dependable is having good and timely communication skills.

**Practices and practicing:** Learn the practices and procedures of each rotation. Each subspecialty or rotation will have specific practices that you will need to learn. Different room setups, different anesthetic plans, different drugs, and equipment. Being properly setup and organized goes a long way towards being successful in a rotation. Learn the physiology and other background knowledge needed in each rotation. Learn and practice the technical skills required in each rotation. Look for opportunities to practice technical skills on dummies and models, so that your encounters with patients go smoother. Yes, you have to know how to stitch and tie to place central lines—so practice these skills in your free time. Once you have all this down, you have the foundation for good decision making, dealing with problems, and will be prepared for the unexpected. You will be ready for the practice of medicine.

**Caring:** Care about and support your coworkers. It is a stressful environment, and we need to look out for each other. Care about your patients—because that's what is of prime importance in medicine. Care about patient experiences and outcomes. Always be patient, kind, and courteous to the ancillary staff. And respectful and low-key with the nurses and, well, you know, with the surgeons, too.

**Self-education:** A resident needs to develop the ability to learn on their own. Although we like to teach, at the end of the day, a resident is responsible for his or her own education. This is just the beginning of what should become lifelong learning. We can't even begin to describe how much has changed in medicine and anesthesia since

we trained. New drugs, new monitors, transesophageal echocardiography, ultrasound guidance, new surgical procedures, changing expectations about patient recovery, the list goes on! The successful physician understands that education is never ending. Learn to use all resources—books, journals, web resources, colleagues, simulations, and meetings. Be curious! We like it when a resident gets interested in a topic, reads up on it, and can teach us something. Be skeptical—don't always accept everything you are told—go back and look at the data to see what the evidence really says.

**Opportunistic:** Part of learning is to look for opportunities to do good cases or help out with big cases. We have residents who always seem to be where the action is, and the opposite is also true. A big case can be intimidating, but it's these opportunities that will help you grow. The more you are exposed to now, the more ready you will be when you are out on your own!

**Perspective:** Always remember the significant medical and legal pressures that rest upon the person whose name is at the top of the chart. You will be there soon enough! Many an anesthesia resident has felt boxed in and even resentful by a "demanding" attending anesthesiologist with an insufficient appreciation of the resident's knowledge and skills only to graduate from training and say a month later, when their name now heads the chart, "Oh, now I get it."

**Be a teacher:** You are working in an environment with a mix of less-experienced residents, medical students, and other learners. Be a good mentor to these coworkers. It sets a good example for those junior to you. In a successful program, we are all working together to develop each other's skills. The other half of becoming a lifelong learner is to become a lifelong teacher!

## The Resident Viewpoint—What Makes a Great Anesthesia Resident?

What makes a great resident physician? The impractical but honest answer is as follow: A great resident knows every answer before the question is asked. A great resident works in a way that makes everyone else's job easier. A great resident interacts with others in the exact way that makes them comfortable, yet pushes them to be the best version of themselves. What makes these answers not actually attainable are human nature and the unique demands placed on resident physicians. Residency is a period of training with evolving expectations, innumerable stressors, and little time for rejuvenation. It is the intertwined roles of learner, healer, coworker, teacher, and scientist. Most people when asked the above question respond with conscientious behaviors (trustworthy, detail oriented, proactive, personable, hardiness) or skills (clinical, communication, leadership, resilience). One could argue that, yes, a combination of exceptional behaviors and skills are needed to make a great resident; but

more simply a great resident understands balance and situational awareness, that is, how to utilize a given attribute in a specific situation. So let's look at some of the roles of the resident.

**The role of the learner:** Residency is a marathon not a sprint, yet it often feels like hundreds of days of sprinting back to back. There is so much to learn in such a short period of time and from so many different experts. A great resident understands how to balance short- and long-term learning objectives. A great resident utilizes enthusiasm to prepare for an upcoming case, and a strong work ethic to review and solidify knowledge over a prolonged course. A great resident demonstrates vulnerability in a new learning environment yet courage in seeking out those experiences. A great resident can balance the humility of learning from others with the confidence to try-fail-overcome and succeed. Great residents know when to push themselves and also when to ask for help. A great resident accepts that every learning opportunity is another human being's pathology and respects the journey of medical apprenticeship to integrate education with patient care. (For example, sometimes the attending will take over a procedure in a difficult patient or emergent situation!)

**The role of the healer:** Teaching programs train residents to become competent, capable independent practitioners who take on the awesome responsibility of caring for patients. During patient care, great residents understand how to balance compassion and empathy with realistic patient expectations and outcomes. They coordinate listening to a patient's concerns with imparting excellent medical information. Great residents are able to walk the line between patient-centered and outcome-driven care, and do so with excellent communication. Great residents constantly practice with the highest level of integrity and give patient encounters total devotion.

**The role of the coworker:** No provider in medicine works in a vacuum, especially residents in successful multi-disciplinary teams. Great residents create environments that encourage diversity of thought yet can de-escalate confrontations and provide win-win solutions. Great residents find equilibrium between being a team player supporting a colleague and positive peer pressure encouraging others to improve. Great residents are sensitive to the professional and personal struggles of their coworkers, while at the same time leading by example and displaying positive energy and enthusiasm.

**The role of the teacher:** As residents progress in their training, they transition from learner to mentor. Great residents work with the efficiency of an attending, yet display patience while providing guidance to juniors. Great residents are able to delegate responsibilities and coordinate education experiences with kindness. Great residents push juniors to excel while anticipating obstacles and supporting inexperience.

**The role of the scientist:** Residency affords junior physicians the opportunity to learn both the art and science of medicine. Great residents are curious and forward

thinking, constantly acquiring new knowledge and integrating evidence-based medicine into their practices. Great residents balance attention to detail with the best system practices to provide both specialized and standardized care. In other words, they learn and follow consensus guidelines, but also appreciate that sometimes a specific patient may need a different type of care. Great residents find harmony in efficiency and thoroughness.

**The role of the survivor:** It is no secret that residency is difficult. Residents work extended hours without sleep, proper nourishment, exercise, and emotional or spiritual support. And while the validity of this environment is a discussion for another day, great residents will arise above this climate. Great residents balance resilience with mindfulness and awareness of fatigue. (Beware driving home when you are impaired from fatigue!) They find unique ways to recuperate and reenergize themselves. Great residents take pride in sacrificing for others yet stand united against hazardous working conditions.

**The role of anesthesia ambassador:** From the first day of training, anesthesia residents represent their department and specialty. Anesthesiology is a unique medical field as it is one of the only medical specialties in which there is a minute-to-minute shared collaboration of care of the patient. Great residents balance taking extraordinary care of anesthetized patients with the wishes of the collaborating surgeon, obstetrician, gastroenterologist, pulmonologist, cardiologist, etc. A great resident knows when to educate our colleagues on the other side of the drape, when to compromise, and when to call in the attending anesthesiologist for backup. And despite a reputation for being one of the "unseen" medical specialties, anesthesia residents range pretty far and wide in the hospital—from helping with emergencies in the trauma bay, to codes on the wards, and to being perioperative experts in the ICU and floors. Like all ambassadors, residents will need to draw fully on their skills of negotiation and diplomacy.

## TAKE HOME POINTS

- Great residents are able to balance their many roles with flexibility, responsibility, and grace.
- A great resident is a mature, caring team player with excellent communication skills. He or she strives for excellence as both a student of their profession and a mentor to their colleagues.
- Great residents know that patient care is the center of our profession, and pursue it with empathy, integrity, and zeal. They continuously develop their knowledge and skills, so that they will be ready to go out and be an excellent practitioner of medicine.
- Every single one of these points also applies to the established or more senior

anesthesia practitioner. Really, if we wrote a chapter on "What Makes a Great Anesthesia Attending," it would say the same thing!

## Suggested Readings


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# SECTION XIV

# LEGAL

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# Introduction

Cobin Soelberg, MD JD MBe

Physicians and Lawyers. It is an easy cliché to state these two professions are often viewed as adversarial. However, there are many areas of an anesthesia provider's professional life that are impacted by lawyers and very few of them involve the courtroom. Think of straightforward interactions such as medical and DEA licensure. More than that, healthcare is one of the most regulated industries in the United States. Recent Federal law expanding access to healthcare only increases the requirements and reporting demand on practitioners. Regardless, the law and legal system will play an important role in how we can deliver care to our patients.

In this section there are chapters covering many ways anesthesia providers dig themselves into deeper legal holes: improper charting, lack of clinical consents, abuse of medications, but also not reaching out for help from a lawyer whether you've been served in a lawsuit or other employment issues.

You'll discover what to expect during a lawsuit—the who, what, and when. There is great information on medical charting and recordkeeping, and how to apologize after a medical mistake. You'll also find ways to avoid ending up in court in the first place.

Finally, there is information on challenging ethical issues in anesthesia. What to do with informed consent, refusing to do a case on ethical grounds, what to do with a DNR order in the operating room.

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# A Brief on the Legal Process

Abiona Berkeley, MD JD, Daniel L. Glennon, JD MA, Wilhelmina Moen, and Vincent S. Cowell, MD FAACD

It is important to note that **anyone** can be sued. In 1971, a civil rights action was initiated against Satan and his servants. Whether the devil was ever aware of the lawsuit may be up for debate, but the plaintiff did not prevail. Lawsuits are filed for many reasons, some valid and some not. Merely because an action has been instituted against you, it is neither a finding of wrongdoing on your part, nor a declaration of incompetence.

## Before the Lawsuit

A lawsuit begins with an adverse interaction between the patient and the medical process. The anesthesiologist, as a prospective defendant, may not even be aware of the conflict until the suit has been initiated. There are, however, methods of practice and behavior which may decrease the likelihood of suit or increase chances of early notification or decrease the extent of damages.

As an anesthesiologist, you have to know the procedure. This includes not merely the proposed surgery, but the patient's history and the anesthetic implications. Always provide the best care you can. This includes seeking help from others when needed. All interactions with the patient and their representatives should be respectful, professional, and appropriately informative. Detailed discussions with the patient should be limited to your involvement as an anesthesiologist.

Appropriate assistance should be obtained for any adverse event. This may include consultation with experts and/or notification of the Risk Management team at your institution. The patient should be notified of the event and any possible sequelae. Appropriate contact information may need to be provided in the event that the patient has additional questions or concerns at a subsequent date.

## The "Med Mal" Lawsuit—Who's Who

**Plaintiff/Complainant**—The party alleging injury caused by the Defendant. This may be

a patient, the patient's estate, or representative.

**Defendant**—The party believed to have wronged the plaintiff. Defendants will often be individual doctors, nurses, medical staff, and the hospital. Medical device manufacturers or Pharmaceutical companies can be named as well.

**Lawyer/Attorney/Counsel**—The official liaison to the court system and to other parties to the action.

**Jury**—A group of your peers selected by the attorneys. They are the finders of fact and are entitled to believe all or some or none of the evidence before them in rendering the verdict.

**Expert witness**—A person with specialized knowledge necessary to support a claim or defence. These experts might provide evidence regarding the mechanism of an injury or the type of damages likely to be sustained.

**Judge**—The arbiter of the law. Any points of law which may be in dispute will be settled by the judge. The judge will also decide any motions for evidence, testimony, or summary judgment.

## The Lawsuit

In the 1971 lawsuit against Satan and his servants, the plaintiff alleged that the defendants had set obstacles in his path which caused his downfall. The defendants prevailed not because the action lacked basis, but in part, because the plaintiff failed to provide directions for service of process upon the defendants.

A lawsuit is formally initiated when the plaintiff files the Pleading or the Complaint in a Court of Law. The Complaint sets forth the grievances, the injuries the plaintiff sustained, and the people alleged to be at fault. The Complaint must be served to each defendant in the action.

## Discovery

Discovery is the information gathering portion of the lawsuit. During this process, each party files papers with the court which are also given to all persons named in the lawsuit. In these papers, they request answers to questions and documents that they believe exist and will help prove their case. In addition, depositions are scheduled where persons with information regarding the case are questioned under oath about the events that occurred.

## Trial

A jury awarded $2.1 million to a patient and his family after the patient entered a vegetative state and suffered severe memory and speech deficits and when his tracheostomy site became obstructed. The only defendant found liable was the physician, who the plaintiff's attorney alleged took too long to call for help.

Once Discovery has concluded and any pretrial motions have been determined, the parties proceed to trial. As the trial opens, the lawyer for each party appears before the court and outlines the evidence as they see it, setting forth why they should prevail. The plaintiff, who has the burden of proof, then presents their evidence. After the plaintiff has presented all of their evidence they may close their case and other parties have an opportunity to present evidence if they wish. Based on the evidence produced by the defendants, the plaintiff often has an opportunity to present rebuttal evidence.

Evidence typically takes the form of lay and expert witness testimony. Witnesses are used to introduce evidence in the form of documents such as the anesthesia record, the patient's chart, videotapes, and photographs.

**The burden of proof in a lawsuit rests with the plaintiff**. In a civil action, the burden is to show that the defendant "more likely than not" was the cause of the wrongdoing. In a criminal action, the prosecutor must show that the defendant has violated a criminal statute, "beyond a reasonable doubt."

Once all of the evidence has been presented, each party may set forth their closing arguments. The finder of fact then withdraws to reach a verdict. In a civil court, the verdict may include damages owed to the prevailing party. The verdict is announced in open court.

Any party disagreeing with the verdict may file an Appeal to a higher court. In the Appeal, findings of fact are typically not contested. The fact-finder is granted huge leeway and may believe all, some, or none of the evidence presented by any witness. However, any arguments regarding the application of law may be reviewed. The decision by the appellate court may require a new trial or may simply reverse the verdict. A new trial is costly for most parties and will often cause renewed settlement discussions.

Each party is typically required to bear the burden of the cost of litigation. However, often the prevailing party will request that the court order the opposing party to pay some or all of the costs, including filing fees and attorneys' fees. The grounds are usually that the suit should never have proceeded as far as it did.

## Alternatives to Lawsuit

Lawsuits are time consuming and expensive and there are alternatives which should be considered from the start by all parties. Contractual relationships between the parties

may also require that the parties attempt some or all of these alternatives. As with litigation, the parties are often represented by an attorney throughout these processes.

## Mediation

When the National Football League filed a motion to dismiss an action alleging that they hid the dangers of concussions from the players and their wives, the court refused to rule on the motion until the mediator had sufficient time to attempt to bring the parties to agreement.

Mediation may occur either by the direction of the court or by agreement of the parties. It is a very informal process in which the parties meet often with the assistance of an impartial mediator, to discuss their issues in an attempt to reach a mutually agreeable conclusion to the dispute. The mediator may meet jointly and privately with the parties in an attempt to focus the issues. The process should be made confidential.

## Arbitration

In 2013, Microsoft filed an emergency Demand for Arbitration when Yahoo notified them that all the terms of an agreement intended to help them compete better against Google would not be completed by the agreed deadline. An arbitration decision was made within 18 days.

Parties can submit their dispute for arbitration. This often occurs as a result of a prior contractual stipulation. Some states also have mandatory arbitration requirements for certain types of cases. Arbitration is frequently considered to be faster and less expensive than a trial.

The decision in arbitration is typically binding upon the parties, and subject only to limited review by the courts. However, depending upon the contractual agreement of the parties or the applicable statute, an arbitration agreement may include the right of the parties to pursue litigation in lieu of the arbitration decision.

### TAKE HOME POINTS

- Always be respectful to the patient and to your colleagues. **Hint: If you get into an emotionally charged situation with a patient or representative, pretend that you are speaking to your in-laws or other persons in your life with whom you need to preserve a cordial relationship.**
- Notify your risk management team and your insurer of any potential and actual claims against you as soon as possible. Failure to do so may result in denial of coverage both for legal representation and for the claim.
- If there is a point of dispute between yourself and your counsel you may need to seek

alternate representation, particularly if your counsel is representing other parties as well.

- Mediation and arbitration are typically less expensive and faster than litigation and are viable alternatives to lawsuit. Do not look upon these dispute resolution processes as a failure to prevail. Only about 2% to 3% of civil lawsuits go to trial.
- Just because you have been sued does not mean that you have done anything wrong. Stay calm and try not to take it personally.

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# How "Not" to End Up in a Closed Claims File—Lessons Learned From the ASA Closed Claims Project

Lorri A. Lee, MD and Karen B. Domino, MD MPH

## Overview of the ASA Closed Claims Project

One of the best ways to avoid common anesthesia errors is to review cases where patient injuries occurred, identify alternative practice management that might have avoided the adverse outcome, and incorporate those lessons into one's own practice. Quality assurance (QA) or continuous quality improvement (CQI) committees for anesthesiology departments and hospitals use this strategy to improve patient safety. However, some adverse outcomes will occur despite good medical management, and may eventually result in lawsuits.

Similar to QA or CQI committee review of adverse outcomes, review of claims or lawsuits filed against anesthesiologists may also identify factors associated with specific patient injuries, as well as factors associated with patients' decisions to file a lawsuit and unfavorable judgments against anesthesiologists. Recognizing the value of these claims, the American Society of Anesthesiologists established the Closed Claims Project in 1985 to collect detailed information from these insurance company files from across the country by trained anesthesiologist reviewers.

For those unfamiliar with the medico-legal system, "closed claims" refer to claims that were filed by patients against doctors, allied health professionals, or hospitals for medical malpractice, and were dropped, settled, or preceded to trial with a resulting judgment. The litigation phase is completed on these claims, and thus, they are considered "closed." Since its inception, the ASA Closed Claims Project and related Registries has published over 100 articles describing factors associated with particular patient injuries with a focus on improving patient safety. It has been referenced in the Wall Street Journal in 2005 as one of the leading causes of improved patient safety over the last 2 decades in anesthesiology, resulting in some of the lowest medical malpractice premiums for any specialty. It now contains over 7000 closed claims in its

database with approximately 5,200 cases since 1990. This chapter will focus on recurring themes that are associated with claims with unfavorable judgments taken from the ASA Closed Claims Project to better inform the reader on how not to end up in a closed claim.

## Consent

Though consent is frequently an issue in medical malpractice claims, it is rarely the sole reason for the lawsuit, and is usually associated with an adverse outcome. The consent issue has been likened to an anniversary card—"obtaining one does not guarantee you a good time, but you're asking for it if you don't get one." Consent issues may arise for a variety of reasons: (a) inadequate disclosure of the risks of a procedure—e.g., risk of postdural puncture headache after a subarachnoid block; (b) failure to obtain consent for a procedure—e.g., performance of a regional technique under general anesthesia; or (c) documentation of refusal of care when a patient refuses your recommendations—e.g., patient with severe chronic obstructive pulmonary disease and congestive heart failure refuses a regional technique for ankle surgery.

Items for consent discussion should include common complications, as well as any rare devastating complication that the typical patient would find important to decide on a particular treatment. However, they should not be used to list all possible complications, as patients would lose sight of the major concerns. Documentation of the risks and benefits discussion with patients is key to minimizing medicolegal issues surrounding consent. Certain states or malpractice liability companies have a requirement for a separate anesthesia consent form with a patient signature.

**Case:** An approximately 60-year-old female for an open urologic procedure under general anesthesia. As the surgeon left the OR, he asked the anesthesiologist to place an epidural catheter for postoperative pain management. This had not been discussed by the anesthesiologist during the preoperative evaluation. While the patient was still anesthetized, the anesthesiologist attempted placement at two thoracic levels, but was unsuccessful. In the PACU, the patient was noted to have a flaccid right leg and minimal movement of her left leg. An MRI demonstrated a lesion in the thoracic spinal cord at the attempted epidural insertion sites level with edema above and below. **Payment amount was approximately $350,000.**

## Preoperative Evaluation

Issues surrounding preoperative evaluation in closed claims usually involve (a) lack of documentation of an airway examination in cases of unsuspected difficult intubation; and (b) lack of follow-up on abnormal preoperative tests (frequently ordered by other

healthcare providers) in cases where the delay in diagnosis, treatment, or consultation resulted in harm to the patient (e.g., chest x-ray with new cancerous lesion or abnormal EKG with a subsequent perioperative myocardial infarction). These issues emphasize the importance of performing and documenting a thorough preoperative evaluation, and addressing any abnormal test results with appropriate treatment, consultation, or referral.

**Case:** A 50ish-year-old male presented for a transurethral prostatic resection under spinal anesthesia. The patient's EKG showed "ischemic changes with possible myocardial infarct." The EKG was not reviewed by the anesthesiologist or the urologist prior to surgery. There was no medical or cardiology consult for the elective procedure. The patient developed chest pain on the first postoperative day and a diagnosed myocardial infarction on the second postoperative day. The patient eventually had coronary artery bypass graft surgery. A lawsuit was settled out of court for failure to diagnose the myocardial infarct prior to surgery and for the lack of consultation. **Payment amount was approximately $200,000.**

## Changing of the Guard or "Handoffs" With Poor Communication

In this age of same day surgery admissions and outpatient surgery, the frequency of one anesthesia healthcare provider doing the history and physical examination while another provides the anesthetic is an everyday occurrence. Pertinent medical information may be lost, or specific patient promises may not be honored when poor communication occurs. Thorough documentation of any discussions with patients regarding their health history or specific wishes regarding their anesthetic management should help to avoid this problem. Patients may assume that both parties effectively communicated with each other, and that they have no need to repeat their questions, concerns, or information provided to the first anesthesiologist. Any unusual issues should be communicated directly between healthcare providers. Similar strategies of good documentation and direct communication during "handoffs" during operations should improve patient care and minimize liability exposure.

**Case:** A roughly 50-year-old female presented for major reconstructive spine surgery with instrumentation. Two anesthesiologists and two CRNAs were involved throughout the course of this 8-hour surgery. The first anesthesiologist started the case with the first CRNA, and then left the building to take care of personal matters as he was on call that evening. He assumed the second anesthesiologist had assumed care of the patient, but the second anesthesiologist denied assuming care for the patient, except to approve an

order for Lasix by the first CRNA for low urine output (less than 200 mL urine was measured during the first 6 hours of the case). During the 5 hours the CRNA was left unsupervised, she failed to recognize hypovolemia, and treated low urine output with furosemide, and allowed the systolic blood pressure to run in the 80s for 5 hours in a hypertensive patient. The CRNA claimed the surgeon requested deliberate hypotension, but the surgeon denied this allegation during deposition. No arterial line was used and no blood gases were sent. The patient awoke with permanent bilateral blindness secondary to posterior ischemic optic neuropathy. There was no documented preoperative plan, and no anesthesiologist signature on either the preoperative form or the anesthetic record. Because of the concern that the jury would view abandonment of the patient by the anesthesiologists harshly, **the case was settled for over $300,000 before going to trial.**

## Documentation (or Lack Thereof)

Inadequate documentation of the preoperative history and physical and consent, intraoperative events, postoperative care and follow-up, and critical events are a common cause of lawsuits being settled in favor of the plaintiff. The medical record is your line of communication with other physicians and healthcare professionals, and it is also the legal record. Routine care such as a preoperative history and physical and intraoperative care should be documented on the standard forms provided by your hospital/anesthesia group with your signature and date as it demonstrates good care.

Although one may not have time to document during a crisis, a thorough detailed description of the events and actions taken should be written at the first available opportunity. Although basic charting of vital signs and medications should be recorded on the anesthesia record for intraoperative critical events, additional documentation should also be done in the medical record in the progress note section as most other specialties do not understand or feel comfortable with the anesthetic record, and it may be lost during storage. Electronic documentation has the added advantage of not being "thinned" from the chart. Only list the facts—events as they occurred—and do not speculate about etiology of the damaging event. As many claims are not filed until more than a year has passed since the event, the documentation also serves as a reminder to you regarding specific details that may otherwise be forgotten. If an event is not documented, the judge and/or jury, and possibly even you, will be less convinced that it ever occurred, and it leaves the impression that you are not careful.

**Case:** A 30-year-old female presents for an emergency cesarean section under spinal anesthesia. She specified in her consent that no residents were to be involved in her care. An attending anesthesiologist and an obstetric anesthesia fellow did the case with

the fellow actually placing the needle over the patient's objections. The first placement was blood tinged and the needle was repositioned one space higher to get clear cerebrospinal fluid. There is no record of level testing in the anesthesia chart. After the baby was born and cord cut, the patient was given valium 10 mg and fentanyl 200 µg. The patient later stated that she felt the entire surgical procedure, was in excruciating pain, and had complained of this during the procedure. There is poor documentation on this point in the medical record. **Payment amount was $305,100.**

## Altering the Medical Record

**Perhaps one of the most damaging actions a healthcare provider can do after an adverse outcome is to alter or falsify the medical record.** Revelation of this behavior leaves the judge and/or jury with the impression of a dishonest and incompetent anesthesiologist/anesthetist whose medical record and testimony cannot be trusted. That impression combined with a significant patient injury leads the average person to assume fault on the part of the healthcare provider. Any additional information that the anesthesiologist wants to place in the chart should be done on progress notes, with entry date and time noted. Never cross out incorrect information after an adverse event, but rather note any pertinent corrections in the progress notes. Law firms may send the medical records for ink analysis to determine if alterations have been made.

**Case:** A 60-year-old male presents for inguinal hernia repair under spinal anesthesia. The patient received large amounts of sedation. There was a hypertensive episode at the conclusion of the case. The patient did not regain consciousness in the recovery room and died 6 months later. The anesthesiologist submitted a second anesthesia record. He claimed the patient was awake in the PACU. The PACU nurse and surgeon claim that the patient did not wake up in the PACU. The surgeon said the blood was dark during surgery. **Payment amount was $3,000,000!**

## Poor Followup/Communication After an Adverse Outcome

Poor followup and communication after an adverse outcome leaves patients with the impression that you do not care about their welfare, that your time is more important than their health, and that perhaps not everything possible was done on their behalf to treat the complication. Although anesthesiologists have very busy work schedules during these times of "high efficiency" and a focus on "decreased turnover times," followup of patients and their complications with appropriate referral should occur with proper documentation. Failure to recognize the deterioration in the patient's condition and investigate with appropriate intervention increases liability exposure.

Followup demonstrates to patients and juries that you are a professional and care about the welfare of your patient. Even though it may be uncomfortable to see patients after an adverse occurrence, particularly when there was some potential inadequacy of care on your part, followup is an essential part of handling adverse outcomes. **One study on medical malpractice that looked at the reasons patients and/or their relatives file claims showed that only 15.6% to 37.1% of patients were satisfied with the amount of information provided about an adverse outcome, the clarity and accuracy of explanation, whether the explanation was delivered sympathetically, and with the overall view of the explanation.** Similar results were found in a study of 45 plaintiffs' depositions of medical malpractice where 32% of the depositions contained statements concerning patient desertion by physician, 29% with devaluing patient and/or family views, 26% with delivering information poorly, and 13% with failing to understand the patient and/or family perspective.

## What to Do

) Once the patient is stabilized or recovered, your first call should be to your Department Chair or Group President and then hospital risk management and your malpractice insurance company.

) Provide regular followup on the patient and arrange appropriate referral care.

) Find a quiet, private comfortable location for the discussion in person and minimize interruptions (e.g., have a colleague carry your pager).

) Use simple, direct language delivered in a warm, caring, and empathetic manner.

) Demonstrate that you are actively listening by paraphrasing the patient/family's words and showing interest in the patient's welfare.

) Let the family know that there is a plan for continued treatment.

) Express concern for the patient.

) Make yourself open and available to the patient/family.

) After the adverse occurrence has been thoroughly reviewed by all parties, and if the adverse outcome was a result of a medical error, a statement of remorse or apology (after speaking with risk management), full disclosure of events, and corrective actions to be taken should be discussed. Make sure that your state law allows apologies to patients without incrimination.

0) Always be honest with the patient/family.

1) Document your conversations with the patient/family including their responses and the plan of action.

## What Not to Do

) Do not profess guilt or blame other healthcare team members. You can and should still apologize to the patient. Remember that you are apologizing for the outcome, not the approach or your own actions. Anesthesia has recognized complications even if your care is as perfect as it can and they are regrettable when happen.

) Do not blame the patient in any way.

) Do not avoid the patient as the feelings of abandonment are common among patients after adverse occurrences and you may miss sequelae of the complication that require further intervention or referral.

) Do not rush the discussion.

) Avoid technical/medical language.

) Do not joke with your patient about the adverse outcome, especially if he or his family members are in the legal or medical professions. You might nervously try to do this to diffuse tension or establish a rapport with your patient. It doesn't work. To the patient, it feels like a bid for sympathy for the provider.

) In the case of an adverse outcome, the concern should flow from provider to the patient, not the other way around.

) Do not coerce other healthcare professionals to "change their story" or lie.

) Do not submit a bill if the event was related to the anesthetic or as a result of a medical error.

## Maligning by Other Healthcare Providers

One of the underappreciated, but more common, reasons that plaintiffs file claims is the insinuation by other healthcare professionals that there was a maloccurrence. One study found that 17 of 31 plaintiffs reported that other healthcare professionals had either directly or indirectly suggested that the care provided by the defendant had caused the patient injury. Of these 17 claims, 71% of the "other healthcare professionals" alleging maloccurrence were the subsequent consultants who were brought into the case because of the adverse occurrence. For anesthesiologists, one of the potential avenues for miscommunication about an adverse occurrence is through the surgeon. Therefore, the

anesthesiologist should always accompany the surgeon for any discussions with the patient/family. "Charting-wars" with surgeons or other healthcare providers should be avoided as this behavior makes everyone involved look incompetent and only weakens defense of a case should a claim be subsequently filed.

**Case:** A patient in his mid-30s with a history of hypertension, with a preoperative blood pressure of 140/70, presented for extensive 3- to 4-level spinal fusion. The surgeon requested the systolic blood pressure in the 90s on multiple occasions and insisted that the blood pressure was too high and that was the cause of the bleeding. The anesthesiologist asked the surgeon on several occasions to control the bleeding better with the Bovie. The case eventually ended after 9.5 hours prone time (scheduled for 5 hours) and an estimated blood loss of 4,000 mL. The patient complained of blindness the first postoperative night in the ICU. Surgeon's operative note and addendum dictated 2 days postoperatively was highly inflammatory and accusatory and critical of the anesthesiologist's care. He said the anesthesiologist kept the blood pressure too high causing excessive bleeding and used too much crystalloid causing the patient's blindness." **Jury ruled in favor of the defendant anesthesiologist, but cost of defense was $139,707.56.**

## TAKE HOME POINTS

Although adequate medical knowledge is essential for good patient care and avoiding adverse outcomes, not all adverse outcomes can be prevented, and medical misadventures occur. Other factors, aside from good clinical care, which are important to minimize your involvement in lawsuits include:

- Document PARQ and consent with patient.
- Perform thorough preoperative evaluation and follow up any abnormal test results or studies.
- Good communication and followup with colleagues regarding any pertinent patient health issues or discussions.
- Thorough and legible documentation of all perioperative care, with special attention to critical events.
- **Never alter the medical record.**
- Engage in a thorough and open discussion with the patient and/or family regarding adverse outcomes and provide a plan of action with appropriate referral or consultation. Don't joke in any way about the adverse outcome.
- Continue followup with patient and family and make yourself available to avoid feelings of abandonment.

- Make every effort to be present for any discussions by other healthcare providers regarding the adverse outcome to avoid any miscommunication.
- In contested cases where providers are in disagreement about the care received, the hospital-appointed lawyer may not be able to represent both parties. Do not be afraid to ask for an individual lawyer that only represents you.
- Document all patient followup in the chart: phone calls, office visits, and other followup. It is the right thing to do and shows concern for your patient.

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# The Anesthesia Closed Claims Project—What's Trending Now?

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It is to the everlasting credit of the specialty of anesthesiology that we were the first medical specialty to develop a Closed Claim Database. The Anesthesia Closed Claims Project is an ongoing national effort to improve patient safety by understanding where, how, and why patient injury was happening.

The American Society of Anesthesiologists established the database in 1984 in response to rapidly escalating professional liability premiums and is funded by the Anesthesia Quality Initiative. To date, the database is comprised of more than 9,000 closed claims. The research office of Anesthesia Closed Claims Project "resides" at the University of Washington. The Project is a collaborative and multidisciplinary initiative. As part of the overall Project mandate, individual registries have been developed including the NINS registry, the Obstructive Sleep Apnea Death and Near Miss Registry, the Postoperative Visual Loss Registry, and the Anesthesia Awareness Registry. Publications using closed claims data are also further aggregated on 25 different topics including obstetrics, pediatrics, awareness, eye injury, nerve injury, and trauma.

The Project's website is www.asaclosedclaims.org.

## What's New in the Database?

Early on, most claims involved anesthesia care within the operating suite for surgical anesthesia. However, reflective of the changing practice of anesthesia, over the last 20 years or so, only about 65% of all closed claims relate to surgical anesthesia in a traditional operating room setting. While surgical anesthetic claims have been decreasing, claims related to both chronic and acute pain management have seen a steady increase (18% and 9%, respectively, of claims since 2000).

As anesthesia providers will also attest, non-OR anesthesia and MAC anesthesia cases continue to grow at a healthy clip. Since the 2000s, the number of claims for incidents while the patient was under MAC anesthesia increased five-fold, from 2% of

claims in the 1980s to over 10% in recent years. Most interestingly, the claims associated with MAC anesthetics are distinct from surgical anesthetic claims. While death was the most common claim for both MAC and surgical anesthesia, it represents 38% of the MAC claims.

Other leading claims include medication overdose, especially co-administration of propofol and an opioid or benzodiazepine (representing over half the claims of over sedation), ASA physical status greater than 3, **remote procedural location**, advanced age, and obesity. The majority of the closed claims demonstrated that the injury or poor outcome was due to substandard care, especially lack of monitoring pulse oximetry and/or end-tidal capnography. Most alarming, at least to these authors, pulse oximetry was not measured in 15% of cases and end-tidal capnography was only used in 4/87 claims!

## Specific Injuries and Outcomes

**Death** associated with any type of anesthesia is still the leading negative outcome and the most common of the serious complications in the database (26% of claims). Surprisingly, since the 2000s, claims for death associated with MAC anesthesia exceeded claims for death under general or regional anesthesia. SAMBA has reported that in the present day, approximately 70% of all anesthetics are performed in surgery and procedure centers, and medical offices. A large percentage of these anesthetics are performed without significant airway instrumentation. As the scope of procedures done under MAC and in nonhospital settings have expanded, the combination and doses of potent medications has crept up. Lack of, or substandard, monitoring is a significant indicator for claims resulting in patient death.

**Nerve Injury/Regional Anesthesia** was the second most common serious complication and accounted for 22% of outcome claims. About 65% of the nerve injury claims were temporary and not permanently debilitating. While most block claims are related to surgical anesthesia care (45%), obstetric anesthesia is a close second in claims (38%). It will be interesting to follow any changes to these claims as ultrasound-guided blocks become more common.

**Awareness** is represented by an extensive subset of data in the Project, along with the related clinical complication of awake paralysis.

**Airway** or respiratory-related claims have declined over the years due to better patient monitoring and ASA guidelines for difficult airway management. Airway injury represents 7% of claims.

**Burns** incurred under MAC were a more common claim than burns occurring in general or regional anesthetics. The presence of burn injury claims during MAC is a cautionary and mixed story—frustrating and regrettable that they occurred but largely preventable, since they all virtually occurred when an electrocautery tool was used with supplemental oxygen administered by face mask, nasal cannula, or under a tented drape. In previous decades about half of claimed burns were associated with bags of fluid heated in an attempt to warm the patient and a significant percent of burns were also associated with improper use of warming devices.

## TAKE HOME POINTS

- Claims for care under MAC anesthesia have increased five-fold over the last two decades.
- Appropriate ASA monitoring, including end-tidal capnography, is a must in any anesthetizing location.
- Non-OR anesthesia cases are growing and present unique risks and challenges. You are far away from competent help! Make sure you have all necessary rescue equipment. Your caution and preparation for a remote case should be proportional to the distance from the operating room, anesthesia workroom, and skilled assistants.
- Nerve blocks and regional anesthesia represent a significant number of claims. Follow up and document any patient concerns.

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# A Careful and Complete Anesthesia Record Is the Best Defense Against a Lawsuit

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In the unfortunate event that you are named in a lawsuit, the anesthesia record can be your best friend, or your worst enemy. Because the anesthesia record is the only document that is continuously and concurrently recorded during the course of surgery, **the anesthesia record is often considered the most important document detailing occurrences in the operating room**. The anesthesia record is not only used as a record of anesthesia management, but also of medical and, to a degree, surgical management. For this reason, anesthesia providers must give considerable thought to the development of the anesthesia record, as well as to its utilization. It is imperative that the anesthesia record be accurate, clear, and comprehensive regardless of the complexity of the case and regardless of whether or not complications occurred during the course of the case.

## Components of the Anesthetic Record

The anesthesia and operative record is the medical and ultimately legal document that records an anesthetic procedure. This record becomes part of the patient's permanent medical record and should be as accurate and complete as possible. It provides information to other care providers that may influence the postoperative medical decision making for the management of the patient. All anesthesia providers involved in the delivery of care should sign the anesthetic record, even providers who in the room for a short interval to give breaks. All providers signing the chart should confirm the record's accuracy, and it should include the information in Table 280.1. **The old adage, "If it's not on the chart, it never happened," is not necessarily true** (i.e., intravenous placement procedure does not need to be routinely documented in the absence of complications). However, it is imperative that all significant occurrences be appropriately documented on the chart.

Although the components of the anesthesia record are virtually universal, there is considerable variation among institutions regarding the information to be included in the record: some records are all-inclusive, attempting to cover every aspect of anesthesia

care (i.e., type of laryngoscope blade used, amount of air in endotracheal tube cuff, etc.), while others include little more than the minimum. While there are legitimate opinions that support both extremes, it is imperative that all sections of the anesthesia form that is in fact being utilized by the medical institution within which one is practicing be timely and entirely completed.

### Table 280.1 ■ Essential Elements of the Anesthesia Record

**Patient information:**

- Name
- Medical record number
- Age
- ASA physical status

**Date**

**Location of anesthetic**

**Diagnosis and Procedure**

**Attending and assisting:**

- Anesthesia personnel
- Surgical personnel

**Times:**

- Anesthesia start
- Anesthesia end
- Surgical start
- Surgical end

**Dosage and times or administration:**

- Preoperative medication
- Anesthetic agents
- Other drugs
- IV fluids
- Blood and blood products

**Pertinent events occurring during:**

- Induction of anesthesia
- Maintenance of anesthesia
- Emergence from anesthesia

**(This includes surgical as well as anesthetic "events")**

**Pertinent lab results obtained during anesthetic**

**During the anesthetic, the following should be routinely monitored and recorded at the following intervals (at a minimum):**

- Pulse (q5 min)
- Blood pressure (q5 min)
- Respiration (q15 min)
- EKG rhythm (q15 min)
- Pulse oximetry (q15 min)
- End tidal $CO_2$ in intubated/ventilated patients (q15 min)
- Tidal volume in intubated/ventilated patients (q15 min)
- Peak airway pressures in positive pressure ventilation (q15 min)
- Temperature in patients at risk for hypo/hyperthermia (q15 min)
- Position of the patient and pressure point issues

**Patient's vital signs on arrival to the recovery room**

**Either as part of the anesthetic record or on a separate cover, a preanesthetic evaluation should be documented including:**

- NPO time
- Patient weight
- Pertinent past medical history
- Pertinent past surgical/anesthetic history
- Current medications
- Allergies
- Physical exam with at minimum
  - Airway exam
  - Cardiac exam
  - Pulmonary exam
  - Other pertinent exams
- Pertinent laboratory/study data

ASA, American Society of Anesthesiologists; EKG, electrocardiogram; IV, intravenous; NPO, nothing-by-mouth.

## The Anesthesia Record: Friend or Foe

The anesthesia record, while not the exclusive record of occurrences in the operating room, is the most comprehensive real-time record of intraoperative events. Nursing notes primarily address statistical concerns for billing and equipment function and utilization. The surgeon's operative report, while it describes the procedure in detail, is not recorded in real time, and only superficially addresses medical management of the

patient, if at all. **For those reasons, the anesthesia record is often the primary document reviewed during intraoperative peer review and during the initial stages of litigation, including medical/legal expert review.** It is therefore inevitable that, if one administers a considerable number of anesthetics, sooner or later one's anesthetic record will be examined in a legal setting.

**A properly completed anesthesia record is the best defense in the event of involvement in medical malpractice litigation.** Assuming one's actions are defensible, a clear record of these actions should establish practice within acceptable standards in the event of an adverse outcome. On the other hand, an incomplete or illegible record implies substandard care. As stated above, although there is considerable variation in the detail to be included in anesthesia records, it is critical to complete all main components listed in Table 280.1, as any incomplete section implies disregard. Essentially, if a component is deemed sufficiently important to warrant inclusion on the record, a legal assumption may be made that failure to complete that component, in and of itself, constitutes negligence. An example of such an instance is an atraumatic intubation. If the anesthesia record requires documentation of, or if one routinely documents, atraumatic intubation, failure to address this component on the anesthesia record may imply the intubation as, in fact, traumatic. On the other hand, if this component is never documented, it would be reasonable to conclude that intubation is atraumatic unless documented otherwise. **Without question, the vast majority of lawsuits involving anesthesia care include issues surrounding an incomplete or inadequate anesthesia record.** Proper and timely completion of the record eliminates these issues.

## Potential Pitfalls in Completion of the Anesthesia Record

Entries on the anesthesia record should be limited to a factual representation of intraoperative events rather than expressions of opinion. Implication of another practitioner in the event of complication will not exonerate the anesthesia provider and may raise additional questions during litigation. An effort must also be made to limit the number of providers who write on the record. Although changing providers is not always avoidable, excessive provider turnover raises questions as to continuity of care. In addition, the anesthesia record should be completed as review is anticipated. In the event of litigation, it is expected the record will be prominently displayed in court.

While the anesthesia record is ideally a real-time record of intraoperative events, a complicated intraoperative course often makes timely record completion difficult, at best. When faced with rapid blood loss, severe cardiovascular complications, or other critical events, patient care must take precedence over record completion. Although

electronic record systems (discussed at length below) may be more beneficial than a manual anesthesia record in this scenario, if only a manual anesthesia record is available, the record must be reconstructed as timely and accurately as possible after the event. In this case, the record must be exhaustively reviewed to ensure completion, especially in the event of an adverse outcome. Often, a poor outcome results in significant distress to the anesthesia provider. For this reason, it is beneficial in this scenario to have the record reviewed by an uninvolved peer before the record is finalized. An individual that is not emotionally involved will generally be better equipped to calmly inspect the record for key omissions. Such a scenario is best illustrated by the following case report:

A 50-year-old woman presented for removal of an infected pacemaker lead. During the course of the procedure, when the lead was extracted, ventricular injury ensued, leading to cardiac tamponade and death.

Litigation was instituted against the surgeon, who alleged that the anesthetist was not adequately monitoring the patient, and missed a prolonged period of cardiac arrest. The anesthetist testified that the patient was alert minutes before the fatal event. The circulating nurse corroborated this testimony. However, the anesthesia record failed to support their recollection of the events. Specifically, page one of the anesthesia record ended at 1730, and page two of the record began at 1800. The critical event occurred at approximately 1800. Although both the anesthetist and anesthesiologist involved in the care of the patient, being appropriately distressed after the patient's death, reviewed the anesthesia record, they failed to uncover the gap between the pages. Following the initiation of litigation approximately 6 months later, the error was noted.

While anesthesia care in this patient was likely well within the standard of care, this documentation failure made the case much more difficult to defend. In the end, while the individual anesthesia practitioners were dropped from the suit, the anesthesia group, their employer, accepted some liability in settlement. It is doubtful that any liability would have been incurred if an uninvolved anesthesiologist would have been asked to review the record immediately after the fact as he or she would likely have discovered the error.

## Electronic Anesthesia Records

Although there is some controversy whether electronic anesthesia records are of benefit, or instead create an increased medico-legal risk, the preponderance of opinion among those experienced in employing electronic records is that these systems are of significant advantage. Electronic records provide an accurate, real-time verification of vital signs, drug administration, and performance of procedures. The controversy arises

when short-term abnormalities of vital signs are recorded, or when artifacts are recorded as real. Electronic record systems generally include a means of eliminating erroneous data, and some include algorithms that correct these anomalies.

Like any automated system, electronic record systems are only as reliable as the operator. One must carefully review the record for accuracy, correcting erroneous entries before the record is finalized. As with a manual anesthesia record, failure to review data and ensure accuracy upon finalization of the record may result in misrepresentation of intraoperative events, thereby resulting in a greater chance of being held liable for an adverse outcome. Additionally, it is much more difficult to dispute and/or disprove erroneous entries appearing on an electronic record after litigation has begun—timely review and correction is therefore imperative.

## Additional Uses of the Anesthesia Record

Aside from the obvious legal use of the anesthesia record (i.e., medical malpractice litigation), components of the anesthesia record are often referenced for other purposes. Quality improvement programs make extensive use of the anesthesia record in the tracking of anesthetic complications and the occurrences that most commonly precede these complications. The anesthesia record also serves as the primary billing document for the anesthesiologist. Anesthesia start and stop times, as well as the performance of special procedures, such as arterial and central lines, regional anesthetics, and transesophageal echocardiography must be documented for proper billing and reimbursement to occur. To convey further relevant medical information that influenced decisions and therapy, pertinent lab studies such as hematocrit, blood gases, glucose, etc. that are obtained during surgery are documented, as well as resultant treatment of abnormalities. For the same reasons, surgical issues, including preoperative administration of antibiotics, administration of heparin for vascular procedures, and tourniquet times for orthopedic procedures are also documented on the anesthetic record.

The importance of the anesthesia record is certain to be enhanced in the future. Currently, Medicare has formulated a model that will determine reimbursement for anesthesia services based on “quality” indicators including administration of preoperative antibiotics within 60 minutes of surgery, maintenance of core temperature within specified limits, and other indicators. The anesthesia record will be the exclusive reference in reviewing for specific outcomes. Failure to effectively record these determinants of reimbursement will have a direct effect on reimbursement for anesthesia services. Commercial insurance carriers, while not yet considering these changes, tend to follow Medicare’s lead, especially when potential cost savings are involved.

## TAKE HOME POINTS

- The anesthesia record is a legal document that contains vast amounts of legally relevant information.
- The importance of complete and accurate information entered on the anesthesia record cannot be overstated.
- The statement "If it isn't written on the record, it didn't happen," is not necessarily true. Routine procedures do not routinely warrant a procedure note in the absence of a complication. However, it is important to document all significant occurrences during anesthesia
- The anesthesia record is also a quality improvement tool and serves as a guide for further and/or future medical therapy.
- The anesthesia record is also primary documentation for billing of services.
- The electronic anesthesia record may be helpful when it comes to verification of vital signs and completeness of these entries, but it is not without its own deficiencies (i.e., artifactual data appearing as "real").
- If a complication occurs, the anesthesia record should be reviewed by the care provider(s) as well as an uninvolved party to ensure completeness and accuracy. Although a contemporaneous record is preferable, documentation as to when and why a retrospective entry is included may be of considerable benefit in the event of litigation.

## Suggested Readings


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# Documentation Disputes in the Medical Record—How to Avoid a Chart War and How to Survive One

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A "chart war" is one of most unfortunate situations in all of medical practice. These frustrating situations occur when a medical provider documents inappropriately in the medical record, "blaming" a colleague for complications or other adverse events. For anesthesia providers, this typically occurs when the offending note is entered by a surgeon about some aspect of the anesthetic preoperative evaluation or perioperative course. However, a war-of-words can occur between any two medical providers who document in the medical record, including nursing staff, intensive and postoperative care unit staffs, and other consultants. Unfortunately, there is a high prevalence of conflict in the operating room and intensive care unit and documentation battles can be viewed as one of the types of high-conflict situations where no one wins.

## Don't Start It!

Here is our advice about chart wars: **Do not get involved in a chart war! Do not start a chart war!**

Chart wars create great, and sometimes lasting, antagonism between providers and can be very destructive to not only your legal defence, but the institutions as well.

You must be scrupulously careful that you are never guilty in starting such a contentious exchange. Keep in mind that the perioperative period is the only area of medical practice in which two "equally ranked" practitioners share a patient and a medical record. This has long been recognized as one of the sources of anesthesia-surgery conflict and it makes sense that conflict sometimes creeps into the chart.

As a responsible medical provider, you are responsible for accurately entering **only** factual data relating to the patient and statements about your own medical plan. If you enter an assessment, make sure that it is based on signs, symptoms, laboratory values, and other evaluations. **Do not** enter your opinions or criticisms of another practitioner's care in the medical record. Do not "argue" with their assessment. **If you must disagree**

**with the assessment of another provider, state your assessment and position simply without editorial comment, as if the conflicting note is not there.** It is not your job, nor do you have the knowledge and position to reconcile, into one party line, every assessment made in the chart during a patient's course of care.

If the other practitioner has not leveled a charge at your care, but has entered something clearly wrong (such as the wrong side for surgery), it is preferable to immediately establish outside contact with the practitioner by telephone. If you feel that the patient is at imminent risk due to the practitioner's note and you are sure your facts are correct, write an order that puts that aspect of the patient's care temporarily on hold, without working through the problem in the chart, and then contact the practitioner's chain of command starting with the practitioner. Also contact the risk management chain of command. But remember, the chart **is not** where a peer review or any review for quality management should be conducted.

## If You Find Yourself in a Dispute in the Medical Record

What do you do if you find out that a salvo has been fired at **your** care in the form of an inappropriate note? It is common and understandable to be distressed and/or angry when your medical practice or standard of care is attacked or you are blamed for a complication. Take a deep breath and pause long enough to regain perspective. You will not be passively accepting this situation. You are going to take strong and definite action, but you will not be taking it in the chart itself.

As we stated above, **do not** enter anything in the chart in response to the opening note (shot) of the chart war. **Ignore it** and write your next note as if the accusations had not been entered. Do not attempt to alter or eliminate any existing part of the record. You will put yourself in serious jeopardy by any attempt to do so, which won't be successful by the way.

We then recommend the following immediate steps, depending on the specific hospital and the severity of the situation:

) Call the provider who is doing the inappropriate charting and ask them to stop and retract their previous comment.

) Alert hospital risk management.

) Alert the other person's supervisor or chairperson.

) Alert the hospital's Chief Medical Officer.

) Alert the hospital Chief of Staff or Medical Board Chair.

It is our experience that the risk management team will very speedily put a stop to

any attempts at propagating the conflict in the chart. Chart wars can and will create significant problems in defending any aspect of care that may eventually be litigated.

It is worth noting that a colleague who attempts to open a dispute in the chart or assign blame via a medical record entry is rarely successful in doing this.

## TAKE HOME POINTS

- Chart wars are very unfortunate from a medicolegal position and very frustrating for the "attacked" provider.
- Do not start a chart war!
- If you are the subject of a negative entry in the medical record, do not respond within the chart. Craft your next note in such a way that you make no reference to the offending statements.
- Keep in mind that chart wars are rarely successful for the party taking the offensive position. Often the blame is reflected back to the person who wrote the first note. Lawyers have been through these scenarios before and understand the game being played.
- Call the provider immediately and directly state your request that the behavior cease immediately. Do not further argue the matter.
- Activate the chains of command, starting with Hospital Risk Management.

## Suggested Readings

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# Reading in the Operating Room: Is It Worth the Risk?

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Most anesthesiologists and anesthesia residents have heard the old truism that anesthesia is "95% routine and 5% terrifying." The problem, of course, is that the portions of an anesthetic that can be dangerous for patients are often unannounced, or at least are heralded only by subtle signs. Further, they are often preceded by periods of relative calm, when, superficially at least, there is not much activity on our side of the curtain.

Imagine, then, that the anesthesiologist in charge of a case has settled in for one of those periods of calm. Confident that things are going smoothly, he or she reaches for a novel and quickly becomes engrossed in some very interesting reading. After about 5 minutes, the case suddenly and dramatically takes a serious and devastating turn for the worse. Things do not go well. The family is furious and hires legal representation. During deposition proceedings, their lawyer inquires exactly what the anesthesiologist was reading at the time the patient experienced the critical event. Was it a mystery novel, perhaps? How long was the anesthesia provider reading while the patient was circling the drain?

Above and beyond reading itself, a wide variety of new technologies competing for our attention have penetrated both hospitals and the operating room, often to a great depth. These include computer-based monitoring and record-keeping, smart phones, tablet computers, and ready web access at anesthesia intraoperative work stations. Within the last few years, wearable computers such as eyewear or watches have diffused into this high-intensity space.

Unlike reading a medical journal or textbook in the OR, reading email or texting on your phone creates an electronic record tracking your activities. **Even more damaging, those electronic records are discoverable during malpractice litigation.** Those records can be demanded and reviewed by plaintiff attorneys who may use any pertinent information to establish negligence. The argument against reading or surfing the web in

the OR is that any activity unrelated to the case diverts the attention of the anesthesiologist away from the patient. The anesthesiologist is engaged in another activity and might miss some of the warning signs leading up to a critical event, possibly missing the window to intervene or losing valuable seconds of response time.

Moreover, above and beyond issues of liability, the argument goes that reading in the OR, could send the wrong message to other members of the care team—if the anesthesiologist is so obviously bored that she or he has to read, how important can their task really be? It can be countered that individual anesthesiologists are highly trained at multitasking and when providing an anesthetic to an otherwise healthy patient there is no reason to prohibit a physician from spending time as he or she finds appropriate. Further, they note, there are no data available that suggest reading in the OR is contrary to our primary role as the guardians of patient safety. Some studies have found that a significant amount of the anesthesiologist's time in the OR is dedicated to tasks other than observing the patient—suggesting that there may be a certain, consistent amount of downtime during the provision of an anesthetic. Although it is true that there is not a great deal of data on this topic, there is a body of work assessing anesthesiologist vigilance, somnolence, and related matters that may allow reasoned, though nonevidence-based, conjecture.

Anesthesia is often compared to other fields that demand high performance for long periods of time. The field of aviation, in particular, is often compared to anesthesia. In aviation, it has been noted that serious errors often occur because of minor distractions. This led to the adoption of a policy prohibiting conversations and distractions in the cockpits of commercial aircraft flying below 10,000 feet.

Certainly, new technologies now common in the operating room have enabled anesthesiologists to become much more connected and given them access to vastly greater sources of information for patient management in real time than were available in the past. Online availability of patient records, medical imaging, laboratory tests, and so on can allow efficient use of OR down-time for patient assessment.

A recent article in the Anesthesia Patient Safety Foundation Newsletter described the benefits of our increasingly technologic practice, including some that might be construed as distractions such as texting and use of mobile devices. Because some of the same devices that offer increased connectivity and communication abilities may also degrade vigilance, it becomes important to carefully manage how these devices are utilized.

For example, at least one study has documented a reduction in anesthesia residents' ability to notice changes in pulse oximeter tone when they are exposed to increased visual attractors and auditory distractions. At the same time, other studies have suggested that reading during low workload portions of the anesthetic does not have a deleterious effect on vigilance. It has been pointed out that reading or surfing the internet

during a case differs little from having conversations with OR staff, or playing music. Although these practices do commonly occur, they all appear to fall under the category of external distractions. Insurance carriers appear to consider participating in activities that do not advance the patient's welfare while in the operating room as outside the standard of care. As a result, the medicolegal liability exposure sustained by anesthesiologists who read during a case can be considered quite high. Although lawsuits of this nature are not common, insurance companies have issued opinions suggesting that external distractions should be kept to a minimum during the operative period.

A recent APSF report mentions that there are a small number (13 of 5,822) of adverse outcomes in the Closed Claims Database resulting from provider distraction. These events (loud music, reading, talking on the telephone) were judged to be substandard care the majority of the time.

Although the overall debate on these issues remains inconclusive, previous issues of the APSF Newsletter reported methods that experienced anesthesiologists utilize to reduce boredom in the operating room other than reading:

) Physically move around the room.

) Observe the surgeon and the surgery. Surgeons will of course become fatigued and bored as well as anesthesiologists. Part of our job is to make sure they are not missing an event that could become problematic, for example, compression of the vena cava with a pack, or a hidden bleeder dripping blood on the floor.

) Review the surgery with the operating room staff.

) Check the reserve equipment. Reassess the anesthesia machine and the monitoring equipment.

) Examine the patient.

In another front, with the immersion of smartphones, tablet computers, and even wearable devices such as Google Glass™, the ability to record audio and video in the operating room has raised new patient privacy concerns. Anesthesiologists should be well aware that compliance with patient privacy is mandatory and that texting (and potentially, the use of cameras embedded in smaller devices such as eyewear or watches) may allow the unauthorized capture and spread of protected health information. This type of activity could result in significant civil and potential criminal penalties.

Google Glass™ demonstrates the benefit and potential risk of new technology. With the camera mounted on the user's glass, the user has the ability to read email, take

pictures, and video—all without anyone else's knowledge. Privacy advocates are concerned about this ability to record others without their knowledge or consent, especially concerning in the OR environment when the patient is anesthetized or sedated. However, the potential benefits and uses of this technology are astonishing. Imagine filming a resident as she places a central or arterial line and using the video for critical teaching purposes. Or if a resident or nurse anesthetist wants to show the attending the surgical field or the OR monitors, this can happen instantly with this new technology. Wearable devices, such as Google Glass™, have the potential to provide even more information from the operating room environment at all times.

## TAKE HOME POINTS

- Reading needs to be secondary to patient care; do not read during times in the case when you might be distracted from important events.
- If you are going to read, make sure your insurance and group do not prohibit that activity.
- Consider other activities to prevent boredom that do not distract your attention.
- Select appropriate reading materials.
- **Do not:** surf the web, trade stocks, and so forth.
- Consider the privacy implications of filming, taking photos, and so on and ensure hospital privacy and consent policies are followed.
- If you read, imagine trying to explain to a jury why you were reading that material while your patient developed a complication. If you can't make it sound reasonable to yourself, it won't sound reasonable to a jury.

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# Going to the Operating Room With a Do-Not-Resuscitate Patient

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## Introduction

Cardiopulmonary resuscitation (CPR) is the only medical intervention that can be performed by a nonphysician without a physician's order or the patient's verbal consent. Consent to perform CPR is automatically presumed when the patient is unable to communicate his or her wish. Although CPR has the potential to reverse cardiac arrest, it may also unduly prolong life, cause unwarranted discomfort, and increase emotional distress.

Two central principles of medical ethics guide physicians in medicine: beneficence and nonmalfeasance. Though these tenets are instilled in all physicians, healthcare providers also have a duty to respect the wishes of the patient and his or her family. Patient autonomy reflects the right to self-governance and individuality. **A provider may be forced to accept a patient's medical decision to refuse treatment, even if it results in the patient's death.** Thus, the desire to preserve life without doing harm may conflict with the patient's wishes, and this is often encountered in patients with a do-not-resuscitate (DNR) order.

## The DNR Order

DNR orders were created in the 1970s for terminally ill patients in order to prevent resuscitation from cardiac arrest resulting from the primary disease or its effects. Hospitals noticed a dramatic increase in DNR orders in 1988 following the Joint Commission on Accreditation of Healthcare Organizations mandate that all hospitals must develop formal policies regarding DNRs.

Unfortunately, DNR orders are often poorly worded. They can be vague ("treat me aggressively unless my condition is irreversible"), overly restrictive ("no life support desired"), or out-of-date. Documentation frequently omits the reason for the DNR order, how it applies, when it is valid, what procedures are covered, and what was discussed.

This can be a problem when patients undergoing surgery have not indicated whether the DNR applies in the operating room (OR). Legally, where documentation is unclear or unauthenticated, life-sustaining treatment is presumed and must be administered.

## DNR in the Perioperative Setting

Providers in the perioperative setting are often reluctant to adhere to DNR orders. The decision to suspend or uphold the DNR order has been the subject of much debate. There are three main issues that providers must confront with a DNR order in the OR.

First, by virtue of consenting to surgery, the patient expects to benefit, either symptomatically or functionally, from the procedure. Patients that undergo surgery have a reasonable expectation to survive the operation in order to obtain that benefit. The very objective of undergoing surgery would be redundant if the patient were allowed to die during the operation. Thus, the DNR order opposes the goal of surgery.

Second, the nature of anesthesia increases the chance of cardiac or respiratory arrest by producing profound disruption in normal physiologic functions such as consciousness, circulation, and breathing. Anesthesia frequently involves measures such as assisted ventilation, endotracheal intubation, and intravenous fluid resuscitation that are considered "resuscitative"; anesthesia may also induce cardiopulmonary arrest that may be readily reversible. Further, the survival rate of patients requiring CPR in the OR is very different from patients who have unwitnessed arrests; the difference may be attributed to the OR environment in which patients are continuously monitored and physicians trained to administer CPR are always present. The overall recovery rate of CPR in anesthesia-related arrests is more than 90%. In contrast, cardiac arrests in patients elsewhere in the hospital have significantly lower survival rates (2% to 6% in general wards, 19% in intensive care unit). Therefore, it is relevant to distinguish between arrests caused by the primary disease and those caused by anesthesia in the perioperative setting.

Finally, surgeons and anesthesiologists expect their patients to recover from surgery. No reasonable physician would operate on a patient with the knowledge that the patient will die in the OR. The goal of surgery is neither to kill nor expedite death, but rather to cure, improve, or palliate. In order to accomplish that goal, the patient must survive the operation.

## Alternate Policies for DNR Orders in the OR

Policies that automatically suspend or enforce the DNR order in the OR are not the ideal solution. Automatic suspension of DNR orders in the OR eliminates the opportunity for patients to make informed decisions about their care based on personal values and beliefs. It may also expose healthcare providers to medicolegal liability as a

result of disregarding patient autonomy.

On the other hand, automatic enforcement of DNR orders may have unintended effects on the patient. Certainly, a patient undergoing general anesthesia to improve their quality of life would not want a "do not intubate" order enforced during anesthesia. Automatic enforcement also may expose the healthcare provider to medicolegal liability, as the patient's family may hold the provider responsible for the patient's death.

## Guidelines Related to DNR Orders in the Perioperative Setting

The 1993 statement on ethical guidelines from the American Society of Anesthesiologists (ASA) and its subsequent amendments in 2001 and 2013 is a useful guide to treating patients with DNR orders. These guidelines have also been incorporated into the American College of Surgeons (ACS) "Statement on Advance Directives by Patients: Do Not Resuscitate in the Operating Room," and the American Academy of Pediatrics (AAP) guidelines for pediatric patients.

**The guidelines discourage policies that automatically suspend or enforce DNR orders in the operating room, as either of these policies "may not sufficiently address a patient's right to self-determination."** Instead, the ASA recommends that all physicians involved discuss with the patient or surrogate, before surgery, the appropriateness of upholding the DNR order during the operation. The ACP and AAP have termed this approach, "required reconsideration." It is also recommended that the provider distinguish between full resuscitation, procedure-directed limited resuscitation, and goal-directed limited resuscitation. The procedure-directed approach focuses on careful consideration of specific interventions that are likely to be used during the operation. Goal-directed limited resuscitation focuses on the patient's goals, values, and preferences, rather than on specific procedures. This latter approach may allow the anesthesiologist and surgical team "to use clinical judgment in determining which resuscitation procedures are appropriate."

## Approach to the Perioperative Patient With a DNR Order ("Required Reconsideration")

These guidelines provide the basis for an approach to the management of patients with DNR orders in the perioperative setting:

) It is vital that in all cases the anesthesiologist and surgical team meet with the patient and/or surrogate preoperatively to discuss the roles of the anesthesiologist and the surgeon during the operation, and explain that some resuscitative measures are routine. Adequate time must be made available to address any ethical issues that may arise.

) If the patient decides to suspend the DNR order, then the period for which it is suspended and the conditions for reinstatement should be specified.

) Specific requests should adhere to institutional policy and professional society guidelines, and should be reviewed by the entire OR team before surgery.

) It may be necessary to involve the institutional ethics committee for difficult situations.

) It is essential to carefully document the preoperative discussion along with specific requests made by the patient in the medical record.

## Conclusion

A well-informed patient or family will be better equipped to make decisions about their DNR order in the perioperative setting. Providers will be comfortable with the knowledge that due consideration has been afforded to patient autonomy without compromise of law, medical ethics, personal belief, or professional guidelines. Required reconsideration is a balanced approach to the management of the surgical patient with a DNR order.

### TAKE HOME POINTS

- A planned operative procedure requires special consideration and communication relating to a DNR order.
- The patient's existing DNR order should be discussed and clarified as to values, decisions, and self-determination.
- An additional careful discussion should take place with the patient to fulfill the obligation for a "required reconsideration."
- Remember that recovery after CPR in the OR is as high as 90%, as opposed to less than 20% in the ICU.
- Automatic suspension of DNR orders in the OR is highly discouraged.

## Suggested Readings


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# Refusal to Do a Case on Moral or Ethical Grounds: More Practical Navigation Through Choppy Waters

Kenneth R. Abbey, MD JD and Marcus C. Stepaniak, CRNA MSA BSN

Imagine that you are assigned by your group to the ambulatory surgery center for the day. Your first patient is a 21-year-old college student for D&E to terminate a pregnancy. She is G1P0 at 8 weeks of gestation. She has decided to terminate the pregnancy because she has split up with the man she was involved with (the baby's father), and she does not feel prepared to raise the child on her own while dealing with the demands of college. Would you feel justified in refusing to perform anesthesia for this woman? What would you think if one of your colleagues refused the case? Is it ever appropriate to refuse anesthesia for a legal procedure?

Imagine now that your group has assigned you to perform anesthesia at the state penitentiary. The governor has asked your group to provide general anesthesia to a 38-year-old male who is a death-row inmate scheduled for execution by lethal injection. A recent execution by lethal injection went badly awry when the IV infiltrated, and the prisoner was believed to have suffered while a second IV was placed and the lethal cocktail given again. To ensure pain-free execution to the current prisoner, the state would like you to induce general anesthesia. When you are satisfied that the prisoner is anesthetized, you will be escorted from the room, and an executioner will administer a large dose of potassium to stop the prisoner's heart and complete the execution. You are informed by legal counsel that your state has a statute making your participation legal and shielding you from any ethical or legal liability. Would you feel justified in refusing to perform anesthesia for this man? What would you think if one of your colleagues refused the case? Is it ever appropriate to refuse anesthesia for a legal procedure?

The issue of refusal of care in medicine is both intellectually difficult and emotionally troubling. To some extent, objective discourse on this topic has been made more difficult because refusal of care in anesthesia is closely associated with the deeply

divisive issue of abortion. However, the issue is broader than that and deserves consideration in the context of other factual scenarios. Questions worth considering include: Is it ever appropriate to refuse anesthesia for a legal procedure? If so, who decides when it is appropriate? How should a refusal be invoked?

Arguments regarding the legal and ethical appropriateness of refusals run the gamut from supporting an absolute right of refusal to concluding that no such right exists for any legal procedure. The arguments for a right of refusal essentially stem from the American tradition of freedom. After all, this country has set forth the right of freedom of expression and religion in its very First Amendment in the Bill of Rights: "Congress shall make no law respecting an establishment of religion, or prohibiting the free exercise thereof; or abridging the freedom of speech …." Certainly, it is argued, if one has a right to freedom of religion, and if his or her religious beliefs (or ethical principles) forbid participation in certain procedures, then no one should be able to force their participation.

The opposing view is well framed by Dr. Julian Savulescu in a recent issue of the British Medical Journal. In his article, Dr. Savulescu states that "[w]hat should be provided to patients is defined by the law and consideration of the just distribution of finite medical resources" and further that "[i]f people are not prepared to offer legally permitted, efficient, and beneficial care to a patient because it conflicts with their values, they should not be doctors." He notes that it is inefficient and inequitable for a large percentage of doctors to refuse to participate in abortions because patients are then required to "shop" for doctors who will perform a legal service. He further notes that inconsistent moral positions of physicians lead to inconsistent care and discrimination. It could be argued from Savulescu's thesis that cases of abortion and execution are distinguishable because the abortion is beneficial to the patient whereas execution is not.

However, that distinction is likely to be lost on the death-row inmate, who would probably believe it beneficial to be anesthetized by a licensed anesthesia provider before being put to death rather than be sedated by an amateur. If doctors are required to provide any legal, beneficial service requested by patients, could anesthesia providers ethically refuse to provide anesthesia to a death-row inmate who requested to be properly anesthetized prior to lethal injection? Would the same ethical considerations apply to assisted suicide in a state where it was legal?

In the United States, refusal to do a case is legally permissible to some extent in most states. Legal support for refusal comes from multiple sources, is often specifically targeted at certain types of cases or objections, and, not surprisingly, is highly politicized. At the Federal level, just months after the Roe v. Wade decision (finding a constitutional right to abortion), the Church Amendment, 42 USC Section 300a-7, was

passed which released individuals who refused to perform abortions or sterilizations on moral grounds from compulsion via certain federal funding. More recently, Title VII of the Civil Rights Act mandated that employers accommodate religious beliefs of employees to the extent that such accommodation does not cause undue hardship.

Among the states, 49 provide for at least a limited right of refusal on ethical grounds for healthcare providers. Twenty-five of those states provide a right of refusal only with respect to performing abortions. In Oregon, for example, Or. Rev. Stat. Section 435.225 states that no hospital employee is required to participate in an abortion. In Mississippi, the Miss. Code Ann. Section 41-41-215 provides broadly that healthcare providers may decline to comply with healthcare decisions for reasons of conscience. Vermont alone offers no right of conscientious objection.

Since Federal and state laws support some right of refusal to healthcare providers and in reaction to specific situations, some hospitals and professional organizations have developed policies regarding whether, when, and how healthcare providers may refuse to participate in care on moral or ethical grounds. At our institution, for example, hospital policy states that "When [a health-care professional's] belief system prevents him/her from being directly involved in a legally available, medically recognized intervention, the [professional] will not be required to be directly involved in initiating such intervention."

Recently, the American Society of Anesthesiologists was compelled to respond to the issue of lethal injection with a "Message from the President." The case set forth at the beginning of this chapter involving a request to provide anesthesia for lethal injection is not entirely hypothetical. In fact, in February of 2006, a federal judge in California issued an order requiring that an anesthesiologist personally supervise lethal injections. The anesthesiologist would be present to assess depth of sedation before the lethal injection was given. The AMA and ASA reacted, with the President of the ASA stating that "[p]hysicians are healers, not executioners." Subsequently, the ASA issued the "Message from the President" that reviews the state of affairs regarding execution and then notes that while the "ASA does not have a detailed position on anesthesiologist participation in lethal injection" it does support the AMA "position regarding physician nonparticipation in executions." The ASA President advised the membership to "be well informed on the subject and steer clear."

The challenge of conscientious objection does not end with an anesthesia provider's determination to refuse participation in a given procedure. Rather, the determination to refuse imposes both obligations and liabilities on the provider. At our institution, for example, hospital policy provides that a practitioner refusing involvement in an intervention must "refer the patient to other persons who will either provide the intervention or facilitate appropriate referral" and further that "[t]his process must not

create undue delay, inconvenience, or impediment to receiving requested services for the patient." When healthcare providers fail to inform patients about available interventions or fail to refer them to providers willing to provide those interventions, they open themselves up to potential liability. Thus, for example, a religious hospital that did not inform a rape victim about the availability of emergency contraception was found liable. In another, a fertility clinic that refused to artificially inseminate a gay patient was sued for discrimination. In addition to legal ramifications, refusing to provide care carries its own set of social and professional fallout. Anesthesia providers may wonder: What will my colleagues think of me? Will the patient receive the services they desire/need? Will I face disciplinary action?

Given the complexity of this issue, the authors recommend a pragmatic and careful approach. Here is some practical advice derived from the foregoing discussion and our experience.

## TAKE HOME POINTS

- Read your institution's policy related to conscientious objection, if it has one.
- Take time to investigate your state's statutes or laws related to refusal of care.
- Think hard about your ethical limits and try to imagine situations that might require you to make a conscientious objection.
- If you know you possess a moral or ethical objection to certain procedures, inform your department chair or designated individual before an ethical dilemma arises. Your goal is to avoid assignment to cases that violate your principles in the first place, not to react once the assignment is made.
- If you object to a case that is thrust upon you, decline, but refer your patient to a colleague making certain that you are not, in fact or in perception, an impediment to your patient's choice of care. If you are backed into a corner (e.g., at night on-call), delay the case until a nonobjecting colleague can arrive, if possible; but if this is not possible, be prepared to choose between your principles and your obligation to your patient, and make sure you are willing to pay the price with your job or in court if your refusal results in irreversible consequences for your patient.

## Suggested Readings


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# Dental Injuries—Document Carefully and Do Not Overpromise

Douglas W. Anderson, DMD (Retired) and Kenneth R. Abbey, MD JD

Your first patient of the day is a middle-aged, morbidly obese man for an inguinal hernia repair who happens to have the brightest, whitest smile you have ever seen. During his preoperative interview, he mentions that he used to have terrible teeth but has recently had a "major makeover" including the "caps" that give him his great smile. Of course, he turns out to be a difficult intubation; and while you are sneaking that bougie under an epiglottis you can only see the tip of, you hear the sharp crack of his front caps giving way to your Mac 4.

Injury to the teeth prior to anesthesia, during induction of or emergence from anesthesia, or under sedation is not common. **Nevertheless, such injuries represent the single largest source of claims against anesthesia providers.** The average payment for dental injury is only $1,700. However, because dental injuries constitute 29% of claims, total indemnity payments are substantial. In addition, administrative expenses associated with verifying and paying the claims add significantly to the cost.

Management of dental injuries begins before they occur. The first task for the anesthesia provider is to have a working knowledge of how dental injuries are handled in their institution. Be aware that there is a wide range out there! The author has provided anesthesia care in hospital systems with policies that have ranged from providing no reimbursement for the repair of dental damage (on the advice of the institution's legal department, who feel that would represent a tacit admission of malpractice) to essentially providing free dental care for life. The second task for the anesthesia provider is to have a basic knowledge of dentition (if you can memorize the branches of the brachial plexus, you can master the simple numbering system of the teeth, Fig. 285.1). The third part of managing dental injuries before they happen involves discussion and documentation. Junior anesthesia providers who have never been involved in a dental complication often do not carefully document the examination of the teeth, whereas more experienced anesthesiologists and anesthetists who have seen

dental complications do! Look closely at the teeth and take a minute to jot by number teeth that are missing or hanging by a thread. Sometimes, it is more expedient to note where there are teeth, instead of where there aren't teeth. Also, take note of any open or fresh sockets. This can seem to be costly in terms of time, and junior anesthesia providers are sometimes resistant to doing it. But consider the time required to bronch the patient while you are standing there thinking, "Did we bump that out, or was that the tooth the patient said fell out last night?"

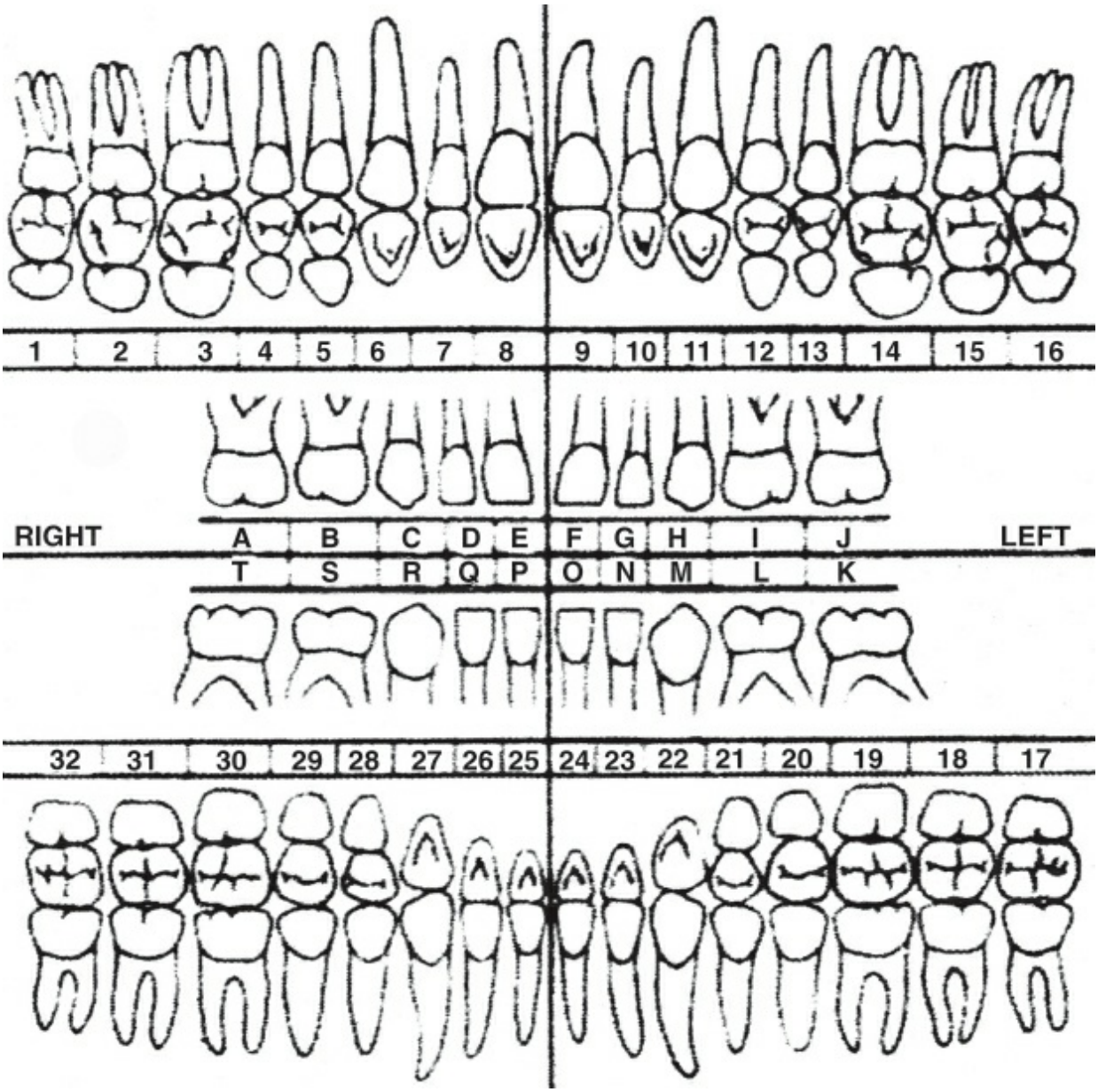


**Figure 285.1.** Number system of the teeth. (From McDonald RE, Avery DR. Dentistry for the Child and Adolescence. 3rd ed. St. Louis: Mosby; 1978:5.)

The preoperative informed consent discussion is a key part of dental management and should always include information about the possibility of a dental injury. Here is

one possible example:

> "As you may know, I need to place a breathing device through your mouth so that I can use the anesthesia machine to keep you asleep and to breathe for you during your operation. It is uncommon, but it is possible to damage teeth or dental work when this breathing device is placed. For example, a crown or a bit of porcelain from your crown may come off, or a tooth may come out if it is extremely loose or if a filling breaks. You've shown me that number 30 is loose, that's one of your lower back molars on the right, so we'll be very careful about that one as well as the rest of your teeth, but I want you to know that damage can happen."

A number of routine circumstances should alert the anesthesiologist to the potential for dental injuries. Anatomic factors that contribute to dental injuries are primarily those that also make airway placement difficult—a large tongue, short neck, limited extension, limited flexion, micrognathia, anterior larynx, and certain pediatric syndromes such as Pierre Robin syndrome.

Instruments may also cause injury, even those designed to prevent dental injury, for example, hard bite-blocks. During emergence, masseter muscle trismus can occur briefly before relaxation and awakening. Some devices like folded gauze, an oral airway, or special props used specifically to protect teeth during emergence can actually contribute to damaging a filling or crown. Although nothing is foolproof, inexpensive folded gauze placed between the back teeth may be the most reliable preventative.

Special care should also be taken during intubation, extubation, mask ventilation, and laryngeal mask placement. In preparation for ENT or facial plastic procedures, for instance, the surgeon may tie the endotracheal tube to the front tooth with a suture, creating forces that dental restorations are not designed to withstand.

Generally, it is best to inform the patient about a dental injury during postoperative recovery. The patient probably already knows that something is wrong because his teeth or mouth may feel different than before. Have the patient seen by your in-house dental consultant, if you have one. If not, take time yourself to explain how the injury occurred and recommend that they visit their dentist or dental specialist as soon as possible. You should also report the injury to your liability carrier and risk management office right away (Do not reassure the patient that "everything will be paid for" unless you know for a fact that this is true!). Follow up with the patient by telephone in a day or two, express your concern, and remind them to seek treatment.

It has been customary for some anesthesiologists to pay for dental repairs when presented with a bill, even long after the incident. However, proper allocation of responsibility is more complex since many factors apart from the anesthesia provider's

actions may have contributed to the injury. Such factors include:

- Poor dentistry
- Restorations that are about to fail, particularly front tooth crowns with a crown to root ratio of 1:1
- Crowns that are too long
- Thin crown porcelain
- Dental neglect and poor oral hygiene

The patient's dentist may help them to understand how the injury occurred and may discourage the patient from making a claim against the anesthesia provider. General anesthesia experience during training may temper the dentist's view regarding the cause of a restoration failure and the culpability of the anesthesia provider. Alternatively, an oral surgeon or an endodontist who has anesthesia experience may help to assess the cause of the injury. An endodontist or a prosthodontist will also be better equipped to evaluate how well a restoration should withstand anesthesia-related manipulations. Occasionally, a patient will call to report the development of a chronic pain syndrome due to restoration after a dental injury, and these have been known to result in tort claims, so maintain a file with as much detailed and complete information as possible.

Dental injuries happen. They are frequently the fault of no one. Weakened crowns on front teeth can sit for years waiting for the unsuspecting anesthesiologist/anesthetist. And yet, any dental injury makes a difference to the patient. Develop a mindset for prevention and know what to do if an injury occurs.

## TAKE HOME POINTS

- Dental injuries are an occupational hazard for the anesthesiologist. Never act smugly or brag that you have never had a dental injury because you will.
- The possibility of dental injury should be part of your informed consent discussion.
- If an injury occurs, tell the patient what happened.
- Report injuries early to your insurance carrier and risk management office.
- There are many reasons for dental injuries. Most are restoration failures that can result from normal manipulation of the airway.
- Develop professional relationships with general dentists, endodontists, or prosthodontists in your community who have anesthesia training.
- Recommend to the patient and their dentist that the injury be examined by one of these specialists.
- Also, recommend that no repairs be made by the patient's dentist until after an examination by an independent practitioner—and provide more than one choice. If the patient's dentist repairs the restoration quickly, no one will be able to evaluate

the cause of the injury.

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# Apologizing to Patients After an Adverse Event Is the Ethical Thing to Do and Just Might Keep You Out of Court

Cobin Soelberg, MD JD MBe* and Katherine M. Seligman, MD

It is your last case of the day and you are starting a redo total hip arthroplasty on a 65-year-old male smoker with COPD and HTN. After a smooth induction and placement of a second IV, you start to give the patient cefazolin—so you can be SCIP compliant!—before remembering he has a cephalosporin allergy. You stop your injection, and unfortunately note the patient getting tachycardic and pruritic. You quickly give diphenhydramine and ranitidine. His vital signs stabilize without the need for additional intervention. The case proceeds and is uneventful. You want to talk with the patient and apologize but aren't sure what the hospital's risk management team will think.

Over the last decade, protected apology and mandated disclosure laws have become widespread throughout the United States. While these laws began surfacing prior to 2001, the release of the Institute of Medicine's report To Err is Human provided an impetus for hospitals and healthcare systems to formally acknowledge medical errors. Since 2001, JCAHO began requiring a limited form of disclosure as a condition of hospital accreditation. Hospitals have responded by creating formal disclosure policies. In 2002, only 36% of hospitals had a formal policy in place; by 2005 that number had risen to 69%.

State legislatures have helped speed up this process by adding apology exemptions into state evidence law. In theory, these laws work by encouraging healthcare providers to apologize to patients after an adverse event has occurred, without the concurrent worry that such a statement can be used against them in court as an admission of fault. Since 2001, over 36 states have passed some form of an "Apology Law." The laws in each individual state vary wildly—some states require oral apologies, while others protect written statements as well.

While state legislative efforts helped, much of the important change is happening on

the ground, at the level of individual hospitals or hospital systems. **Many early adopters of apology programs, such as the Veterans Administration hospital in Lexington, Kentucky and the University of Michigan Health Systems in Ann Arbor, Michigan, have shown numerous positive outcomes.** These include a reduction in both the number and size of financial settlements, increased patient satisfaction, and increased morale among providers who are able to support patients after an adverse medical event.

## What Is a Medical Apology?

Children learn at an early age to apologize—to say "I'm sorry"—when they cause harm to another person. An apology in the medical context is no different. A medical apology is a statement of remorse or concern that an adverse event happened. An important distinction is required; however, it is not placing or accepting blame for a medical error.

There are numerous benefits afforded to patients, physicians, and hospitals from apologizing. Foremost, many studies demonstrate that when medical errors occur, most patients do not sue. Lawsuits stem in part from patient's perception of lack of accountability, transparency, and communication on the part of the physician. An apology can reduce a patient's anger by showing both respect and empathy.

The act of giving the apology can be emotionally and psychologically beneficial to hospital staff as well. In systems that have a strong culture of accountability and a disclosure policy in place, physicians and medical staff report a higher job satisfaction.

## Barriers to Apology

While many physicians want to apologize after an adverse event, there are numerous cultural issues at play that at present discourage disclosure and apologies. Several factors discouraging apologizing include: concern that an apology is viewed as a statement of fault and an admission of breach of the standard of care, a legal system which encourages silence and stonewalling, making a patient aware of an adverse event and inviting legal recourse, and concern that an apology will harm the physician–patient relationship by admitting fallibility.

Both states and local hospitals have attempted to enact policies and statutes that encourage an apology after an adverse event. One goal driving state legislatures to pass apology laws is to encourage more consistent disclosure of adverse events. The carrot comes by the apology being a protected statement. However, the state legislatures provide the stick from the many limitations as to timing and content are mandated. In addition, a limited number of states protect apologies and admissions of responsibility. However, most states only protect the apology itself. States protect oral admissions of

apology in 36 states and counting. Moreover, several states also protect written disclosures as well. It is also important to whom the apology is given with some states requiring it be immediate family or legal caregiver, while other states have broadened that to include domestic partners or friends. Additional considerations include often very restrictive time limits for the apology to be made in order to be protected. The hope is that early disclosure will mitigate the anger driving many lawsuits.

## Advantages of Protecting an Apology

There are several competing tensions at play here—the physician's desire to "do the right thing" for the patient and apologize and the hospitals' interest in reducing the cost of litigation secondary to patient harm. Any steps that reduce these costs—fewer lawsuits, lower payouts, and so forth, must be balanced by the additional administrative costs of a new system. There are both ancillary and nonmonetary benefits. Forthright apologies improve patient's perceptions of their care and the hospital system. Hospital staff morale also improves working within a system that promotes apologies. All of these benefits have been demonstrated in several studies looking at University of Michigan and the VA Hospital System. Ultimately, the patient, family, and public want to understand how an error or adverse event occurred and be reassured that a similar error will be prevented in the future. One of the earliest adopters of a formal medical error disclosure program was the University of Michigan Health System. This system increased error reporting over a period of 7 years from 3,000 reports to over 18,000. Malpractice claims dropped from 121/year to 61/year despite treating approximately 30% more patients over that time frame. Costs—one of the biggest drivers at the hospital level—per claim decreased 50%, and hospital insurance reserves were also reduced. Both hospital physicians and plaintiff's lawyers are pleased with the new process.

While many of us desire to apologize to our patients when an adverse event occurs it is important to understand both the specific laws of your state and, even more importantly, the specific policies of your institution.

Many institutions, including my own, are promoting apology and disclosure as the right thing to do—for the patient, the physician, and the institution. Understanding the particulars of your state law and institutional support will help in achieving these goals.

### TAKE HOME POINTS

- The Joint Commission requires that patients be informed about all outcomes of care, including unanticipated outcomes or errors.
- Disclosure of poor medical outcomes or medical errors provides benefits for the

patient, the practitioner, and for medical institutions.

- Over 36 states have passed "Apology" laws to open lines of communication between practitioners and patients.
- It is important to understand the laws and regulations in the state you practice with regard to admission of fault and apology.
- It is also very important to act within the guidelines of your hospital or institution when considering the tendering of an apology to a patient or family. Work to become familiar with issues when you first join a medical staff. If you are currently on a medical staff and do not understand the local policy and culture, start working on that immediately.
- Let risk management and/or the legal department know when you have had an adverse event and an apology is in order.
- Discuss the form, style, and content of the apology with risk management/legal before offering it, if time allows. However, don't delay excessively if you plan to apologize.
- Be sincere and don't overspin the events. Express concern and let the patient know what steps will be taken to avoid similar events in the future. Never blame the patient.
- Apologizing is never easy. For the novice physician, here is an approach to the apology conversation, "Mrs. Davids, I am sorry that I caused you harm when placing your central line. This resulted in a pneumothorax. Thankfully, we diagnosed this in a timely fashion and can continue monitoring you for now. Can I answer any questions or concerns?"
- Another possible opening sentence is, "Mr. Johnson, I'd like to apologize for the IV line complication you suffered. The back of your hand will be uncomfortable and puffy for several days. I am sorry for any discomfort this is going to cause you. Fortunately, this complication is not dangerous to your hand except in extremely rare circumstances. Again, I apologize."
- Keep the actual apology short. Say you are sorry. Explain the circumstances.
- Let us repeat, NEVER blame the patient (i.e., your body habitus made the line placement more difficult). Allow the patient to ask questions until they have no more questions.

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## SECTION XV

# PROFESSIONAL PRACTICE

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# Introduction

Amr E. Abouleish, MD MBA

Healing is an Art,
Medicine is a Science, and
Healthcare is a Business.

–Author Unknown.

Although we, as physicians, want to focus only on the patient and providing high quality, compassionate, and excellent care to the patient, it is a mistake to ignore the administrative, billing, and business side of our care and medicine. It would be wonderful to live in a world that the Golden Rule is exclusively "Do onto others as you wish them to do onto you," but unfortunately, we live in a world where the other Golden Rule is also true: "He who has the gold, rules."

It would be a mistake to only understand the Art and Science, and not the Business of medicine.

In this section, you will find chapters covering the areas of practice management, including basic business concepts of costs and business plans and marketing, OR management/throughput, and perioperative surgical home. The next set of chapters is focused on job search and evaluating prospective jobs as well as understanding the many different types of "jobs" that are available today. Finally, after finding a position you like, the last two chapters cover employment contracts.

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# Marketing 101: Know Your Customers and What They Need!

Stacey L. Gibbons, MD and Amr E. Abouleish, MD MBA

Providing safe and quality medical care is not sufficient to differentiate you or your group from other anesthesiologists. Therefore, when asking yourself what more can you be doing, the biggest mistake you can make is simply doing what you think is important without considering what your target "customer" wants and needs. In other words, you become unique and indispensable to your customer when you successfully market yourself as the best anesthesiologist (or anesthesiology group)! So you should know the basics of marketing (Fig. 288.1):

) Identify the needs of the customer(s)
) Develop a product or service that meets these needs
) Communicate availability of the product or service to the customer(s)


**Figure 288.1.** Marketing basics.

But even before considering the basics of marketing as noted above, anesthesiologist and anesthesiology groups need to consider yet another important step:

## Identify Your Customer(s)!

For anesthesiologists, the possible types of customers are numerous, including your own group, the different hospitals or facilities with which you are associated, your surgeons, and your patients. Unfortunately, the needs are not all the same for each of these customers; therefore, you will need to prioritize which customer's needs you will try to meet first.

In this chapter, we will only discuss the first step—Identify the needs of the

customer. Our goal is to help you get started in thinking of making yourself indispensable!

## Ante-Up Qualifications

Being well trained, providing anesthesia care, completing documentation, and being board-eligible or board-certified will not necessarily differentiate you from other anesthesiologists. These traits are considered "ante-up" qualifications. In other words, you need to have these just to be in the game. Simply stating: "I provide good anesthesia care" will not identify you as special and/or indispensable.

## Your Group—Initial Job Search, Making Partner, Being a Good Citizen

In an attempt to answer the questions: "What are the needs of my group?" and "How can I make an impact?," the answers should not only be the above stated ante-up qualifications. Instead, you must also consider what will make the group successful and how you can be a part of making this happen. The most common traits that groups want from their members are the following: (1) **good interpersonal skills**—with patients, surgeons, and other staff; and (2) **good work ethic**. In other words, they are looking for "good citizens." Remember, the group starts with the idea that all applicants and members are qualified and skilled clinical anesthesia providers and already meet the ante-up qualifications. Clearly what they do not want or need can be best described as a "difficult child." The group does not want a physician who is disruptive, untrustworthy, or lazy.

## Your Hospital or Facility

What do facility administrators want from the anesthesiology group and anesthesiologists? The answer to this question includes many different activities that are not all clinical. In addition to ante-up qualifications, the facility administrators need anesthesiologists who work well with surgeons (a.k.a. minimal complaints), and contribute positively to patient satisfaction scores. They want physicians who will lead in the area of quality improvement. This often requires projects that lend themselves to operations improvement projects. They want physicians who will serve and lead on the different facility-based committees and take on administrative roles. Obviously, these duties include committees dealing with the OR but they also include nonclinical duties that help the facility run well—quality improvement committees, accreditation teams (e.g., Joint Commission prep team), credentialing committee, and even the medical staff executive board. In other words, the facility administrators want anesthesiologists who

do more than provide anesthesia care (ante-up qualification). If you are involved in multiple essential activities of the facility, you as well as your group can be considered indispensable.

## Your Surgeons

Again, the ante-up qualifications of clinical skills are a requirement. So what else do your surgeons want? At the most basic level, every surgeon wants to be able to do their list of cases with minimal delay or interruptions and have quality anesthesia provided to his or her operative patients. This includes adequate preoperative evaluation done prior to the day of surgery and any issues being addressed before the day of surgery. The surgeons would also **strongly** prefer not to hear complaints from their patients concerning their anesthetic care. Finally, surgeons can be hesitant about working with someone new when one of his/her goals is to know what to expect from the anesthesiologist. Therefore, the first time you work with a surgeon, do your homework (ask your partners and even the nurses and surgical technicians what the surgeon likes and dislikes concerning anesthetic care) and make sure you introduce yourself and ask the surgeon if there is anything they would like done during the case beyond the scope of a standard anesthetic.

## Your Patients

Again, in addition to ante-up qualifications, what does a patient and his/her family need and want? There are many ways to answer this question but the underlying principle to all answers is "meeting the patient's expectations." Therefore, setting realistic expectations is often the first and most important step to having high patient satisfaction. If you or a member of your staff has the opportunity to call the patient prior to day of surgery, then do it! You can tell the patient what to expect—both in events that will occur and in what type of care will be provided. On the day of surgery, we have all observed physicians with good "bedside" manners—they communicate with patients and their families in an honest and straightforward manner, they make the patient feel that they are the top priority for the physician, and they make the family feel that the physician will treat the patient as if he/she was one of the physician's family members. **Simple things go a long way. Do not rush when talking with the patient. Sit if you have the opportunity.** The ability to develop a rapport with your patient and their family members is of paramount importance. And you have a short time in which to do so. So do not waste the time and rush through the interview. Your appearance also is important. Do not appear disheveled. Do not look like you haven't slept all night! You will be shepherding your patient through one of the most unusual and scary experiences of their lives—look like you are up to that set of responsibilities.

## TAKE HOME POINTS

- Do not make the mistake of thinking or assuming that providing safe and quality medical care will be enough to distinguish you or your group. This is a given and assumed for the modern-trained anesthesiologist and anesthesia provider.
- You must identify your customers! And then you must identify their needs, develop a product or service that meets these needs, and then communicate the availability of the product or service that you or your group can provide that will be of service to your customer.
- Your **group** wants a good citizen—that is, a member who has good interpersonal skills and a good work ethic.
- Your **hospital** wants a minimum of complaints from the patients, surgeons, and nurses. They also want help with problem-solving their administrative quality management obligations.
- The **surgeons** want to operate with a minimum of delays and absolutely as few complaints from their patients about the anesthesia staff or procedures as possible.
- Your **patients** want face-time with you—as well as your empathy, confidence, reassurance, and kindness.
- These are only the first steps in a comprehensive "personal marketing" campaign. The next steps and the additional challenges (opportunities!) include thinking more about the needs in your specific situations, coming up with ways to meet these needs, and then if your customer does not know that you have a solution, communicating that effectively to them.

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# Improving OR Throughput: Don't Say "No"

Sandhya Vinta, MD and Amr E. Abouleish, MD MBA

To improve your job security, you do not want to be viewed as part of the problem, but instead as part of the solution. Hence, when approached about addressing a "problem," instead of saying "No!" be willing to take on the issue. One of the most common issues that you will be asked to help fix is Operating Room (OR) throughput.

OR throughput is the current catch phrase for many other terms including OR efficiency, turnover time, late cases, and simply doing more cases. The reality is that improving OR throughput is in the interest of the anesthesiologists as well as the hospitals and surgeons.

In this overview we present three major areas of focus: first case on-time starts, reducing turnover times, and parallel processing.

## First Case On-Time Starts

One of the most common OR performance measurement is the percentage of first cases started on time, a.k.a. "on-time starts." This measurement is simple to measure and understand, and it reflects a good culture—getting the day started on time will lead to better efficiency. But despite its simplicity, getting first cases started on time actually encompasses multiple processes starting at the time of posting of the case to the day of surgery. The process includes surgical paperwork (consents, histories, and physicals) completed and in the patient's chart, correct posting of the procedure, equipment needed available, patient screened preoperatively, last minute labs needed, OR staff on time and prepared, patient in the hospital on time, DSU nurses getting the patient ready on time, transportation, and more!

Understanding what needs to be done to meet the on-time start highlights the danger of an anesthesiology group having incentive payments tied to this measurement, for most of the processes are not under the control of the anesthesiologists.

Measuring the "on-time" start is simple only if everyone agrees what it means to have an on-time start. For most institutions, patient-into-the-OR is the time that is tracked and tabulated, but sometimes institutions will also include the time-out being

done prior to induction as the measurement. By measuring both in-the-room time and time-out time, possible areas of delay are more easily identified and can be addressed individually. For anesthesiologists that take care of pediatric patients, the measurement needs to be adjusted since the time-out is done in the holding area with the parents. In contrast to adult patients, you cannot bring a child back to the OR and then wait for the surgeon to arrive at the hospital.

Despite these reservations, first case on-time starts should be measured and used to identify areas for process improvements.

## Turnover Time

Probably the most common complaint you will hear about OR efficiency is that turnover time is too long. Although you may be frustrated by the implication that you and your colleagues are responsible for long turnovers and the lack of OR efficiency, you do not want to say "No" when asked about working on turnover times. Instead volunteer to lead the effort and then focus the efforts to reducing delays!

Focusing simply on turnover times will not lead to an increase in the number of cases that can be done. For example, if turnover time was 40 minutes and the average case is more than 2 hours, then a 30% reduction in turnover time will only result in 12 minute savings between cases. You would have to have 10 turnovers (or 11 cases) in that OR to save enough time to do one more case. Many turnover time initiatives end up with staff worrying about 1 or 2 minutes leading to wasting much time and effort for inconsequential results.

In contrast, if the focus is on eliminating any delays (defined as turnover time over a maximum amount), then staff will not be concerned whether the turnover time was 20 minutes or 22 minutes. The focus is to have all turnovers below a set goal (we recommend having different goals by the type of surgeries). After meeting the initial goals, one could then make the goals even more ambitious! An additional benefit in focusing on delays rather than all turnovers is that identifying the cause of a delay will usually result in improving an issue that impacts many other cases too. For example, the issue may be that there is not enough transportation personnel available. So if you fix it for one case, you really fix it for many cases.

## Parallel Processes

In 2005, Anesthesiology published a series of articles that examined the improvement of OR operations when parallel processing was implemented rather than relying on series processing (see Suggested Readings). **The underlying principle of parallel processing is that multiple activities can be going on at once rather than having to wait for one task to be completed before doing the next task.** For anesthesiology groups, the two

most common ways this is done are (a) preoperative regional block placement in a block room, and (b) providing multiple ORs for the same surgeon.

Preoperative regional block done in a "block area" allows for the next patient to have their induction of regional anesthesia done while the surgery on the previous patient is being done. Then when the previous patient is done and the room is cleaned and set up, the next patient is wheeled in and can be prepped and positioned almost immediately, eliminating anesthesia induction and emergence time in the OR.

For a busy surgeon who is doing many short cases, the surgeon is given two ORs. For example, while the surgeon is working on patient 1 in OR A, patient 2 in OR B can be induced, positioned, and prepped. Then when the surgeon is done in OR A, he/she can come directly to OR B after talking to the first patient's family. While the surgeon is working on patient 2 in OR B, patient 1 is emerged from anesthesia, OR A is cleaned and set up for patient 3, and patient 3 then is induced, positioned, and prepped. And so forth. This works well when the nonsurgical time (emergence-clean/setup-induction-position/prep) is of similar length as the surgical time. For institutions that do a WHO checklist or time-out before induction, it is a challenge but can be done if the staff, surgeon, and anesthesia teams coordinate a time-outs "one ahead." That is, do the WHO checklist for patient 1 and patient 2 prior to starting with patient 1. Then for patient 3, the time-out is done prior to the surgeon going to OR B to take care of patient 2.

## Reducing Overtime

Even if improving OR efficiency does not result in more cases being done, it can still be successful if overtime or "forced-stay time" (i.e., having to stay past your scheduled shift time) is reduced. In fact, not only will reduction of the overtime result in direct cost savings, the improvement of retention of employees and morale of staff may lead to better performance and even more improvements.

For more information on OR throughput initiatives, we recommend you start with Cima et al.'s description of a thorough initiative done at the Mayo Clinic. For more information about measuring OR efficiency, we recommend you start with Macario's editorial on performance indicators.

### TAKE HOME POINTS

- You will almost certainly be asked to improve OR throughput and efficiency. Don't say no!
- Make sure you understand each and every metric that is tracked as part of "on-time" starts at your institution. Do not ignore these! You do not want to get on the wrong side of an on-time tabulation.

- Understand when reductions in turnover time matter.
- Help your institution explore the idea of block rooms and appropriate parallel processes.
- Read the literature from the last 10 years on operating room throughput. This subject is here to stay.

## Suggested Readings


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# Cost Analysis: You Always Want to Be at the Table

Rene Przkora, MD PhD and Amr E. Abouleish, MD MBA

**Reality check! Remember that someone is looking at YOUR costs, too!**

Facility administrators and finance personnel view operating rooms as well as other anesthetizing sites as not simply revenue generators but also as "cost centers." In contrast to other areas, many of the anesthesia-related expenses are unique to anesthesia care and easily identified as belonging to the anesthesiologist. Therefore, during your career, you are guaranteed to be involved with cost-analyses or cost-savings initiatives, and you will have to defend your purchases, expenses, and the necessity for new equipment and medications. In all these situations, you want to make sure that you are not only At The Table, but at the Head of the Table during these analyses. As you will see below, much of the conclusions from a cost analysis are dependent on what is included in the analysis and on perspective, which is why the anesthesiologists are so essential to these deliberations.

## Cost Definitions

## Costs Are Not Charges

In the past, charges were the only accounting information that was listed for a patient care episode. It is very important not to settle for **charge data** as a surrogate for **cost data** in any analysis. The charge-to-cost ratios are not the same for all services, medications, and supplies.

## Definitions of Costs

An understanding of how costs are defined and categorized will allow you to have the tools to be able to participate in any cost analysis efforts effectively.

### Fixed Versus Variable Costs

A fixed cost is a cost that does not vary with change in the number of patients or procedures. Examples include the cost of an anesthesia machine, and the cost of a secretary or receptionist. A variable cost is a cost that does change with the number of patients or procedures. Examples include the cost of anesthesia medications, and the cost of disposable anesthesia equipment.

### Labor Costs

Most cost accounting analysis will place labor, for example, anesthesia technician salary, as a variable cost, because the analysis usually involves long periods of times (a year or longer). In fact, in the short term, one cannot change these salaries and hence they are fixed. For example, assume an operating room suite employs six anesthesia technicians. Even if the number of cases drops dramatically, you cannot lay off a technician immediately and hence the cost is fixed for this period of time. Similarly, if caseload goes up, then you do not hire additional technicians immediately.

### Direct Versus Indirect Costs

A direct cost is a cost related to direct care of the patient. Examples include costs of anesthesia drugs, and the salary of anesthesia technician. An indirect cost is a cost that is not related to care of the patient. These costs include cost of administrators and laundry services.

### Total, Average, and Marginal Costs (Fig. 290.1)

Using the above definitions, you can now begin to understand the differences between the total cost, the average cost, and marginal cost. For example, an OR is staffed by hospital staff (nurse and surgical tech) and by the anesthesiology group from 7 AM to 4 PM. If all the cases end at noon, and an add-on case that is done from 1 PM to 2 PM, what is the cost of care for this add-on case? The total cost would include all costs including staffing costs associated with that hour, the room costs, and equipment. On the other hand, since the fixed costs (staffing, room) are already going to be spent, the only costs to do the case are the variable costs (disposable equipment and medications). These variable costs are the "marginal cost" for the add-on case, that is, the cost to do one more case. The challenge is if the revenue for the case expected is less than the total cost, then someone can argue the hospital is losing money on the add-on case. On the other hand, if the revenue is greater than marginal cost, then the reality is that the hospital is making money. Similarly, for an anesthesiology group, since the cost to staff that OR is already spent, there is no marginal cost and all additional revenue is profit!

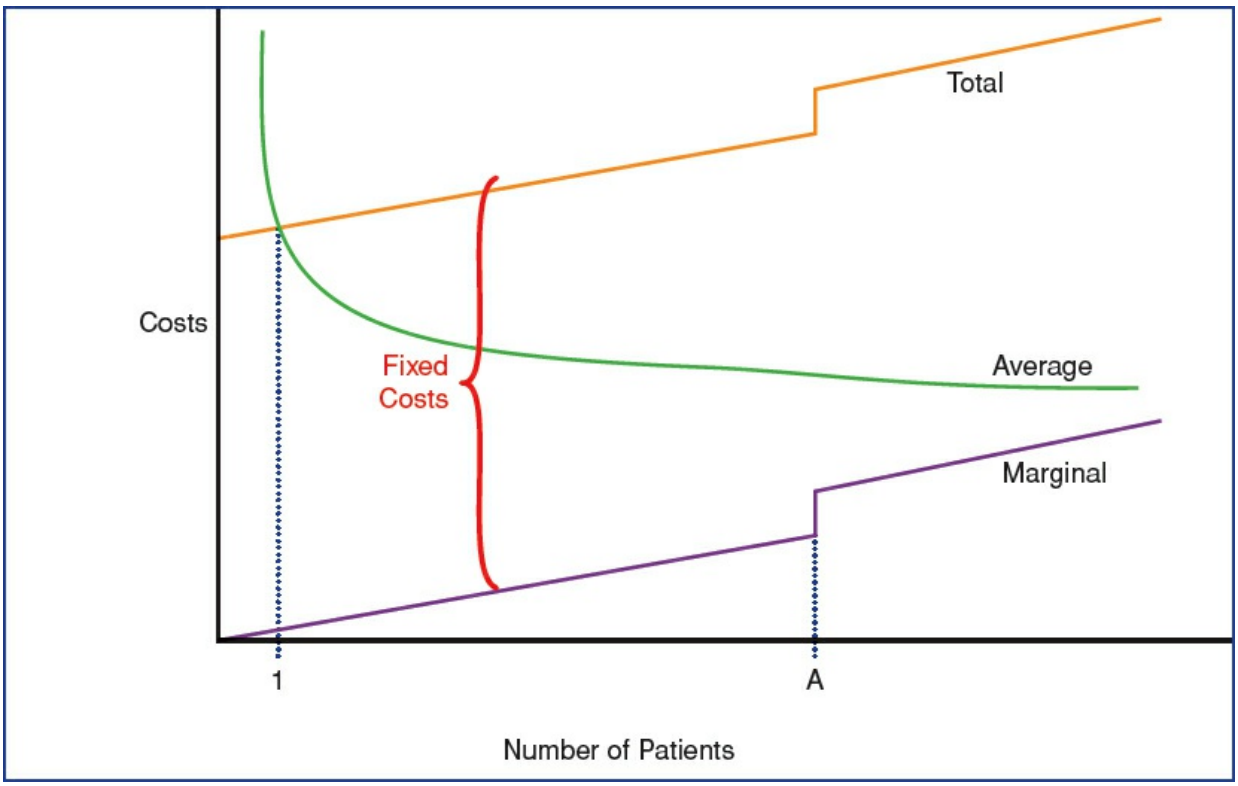


**Figure 290.1.** Total, average, fixed, and marginal costs. The average cost per patient continues to decrease because the fixed costs are spread among more patients. At point A, there is a need to hire more staff and/or more space.

There are situations where the marginal cost actually is higher than expected. For example, suppose the add-on case now lasts to 7 PM. Now the staffing costs must include the evening shift (fixed if already scheduled to be there, or variable if paying hourly overtime).

Average cost is the variable cost for that case and the fixed costs divided by all the cases associated with the fixed costs. Continuing on the example above, if one does two cases in the OR that day, then the fixed costs is split between the two cases. On the other hand, the average cost per case will be less if one did four cases in the OR that day since the fixed costs remain the same, but now split between four cases.

## Perspective—Be at the Table

When discussing costs, the perspective of the analysis determines what costs are included and how they are categorized. If the perspective of the patient or patient's family is taken, then costs of lost work, pain, travel time, and outpatient medications must be included. On the other hand, if the hospital perspective is taken, none of these would be included. It is important to note that a hospital perspective will not include labor costs of nonemployees of the hospital, that is, the costs of anesthesiologists. (If nurse anesthetists are employees of the physician group, they are not included. On the

other hand, if they are employed by the hospital, then their salaries will be included.) Similarly, your perspective will include different costs than the hospital. Finally, a societal perspective is taken for health policy determinations.

For example, different perspectives toward costs are often seen in small hospitals in the decision to provide or not provide obstetric anesthesia services. The hospital may see that the actual costs of supplies are minimal as compared to the increased business or the ability to market as a full-service facility. On the other hand, the anesthesiology group will look at cost of time in the hospital as an important factor to consider.

**The decisions of what is included and not included will often determine the final conclusion of any cost analysis.**

## Cost Analysis: Cost-Minimization Versus Cost-Benefit

When deciding to provide a service as a business plan decision, then the analysis includes a cost-minimization or cost-benefit analysis as well as additional elements including revenue and strategic planning (see Chapter 292—Business Plan 101).

On the other hand, when you want the hospital to include a new medication on the formulary or purchase a new or replacement equipment, you will be asked to justify any new expenditure. Often, the decision-makers are not interested in a full business plan, but simply for you to show why the new expenditures will cost less or the benefits outweigh the costs as compared to the status quo. In the case where the new expenditures will cost less than the status quo, then you simply do a "cost-minimization" analysis. If the new expenditures cost more than the status quo, then you will need to show how the benefits justify additional costs.

These concepts are not foreign to you since you use this type of analysis many times in your life. A great example is when you trying to decide what type of car to buy! If you think getting to work and back is the only important consideration, then the analysis is simply Cost-Minimization, that is, what is the cheapest car you can buy. On the other hand, if you think there are other factors that need to be considered, then you will argue that safety, comfort, reliability, stress-relief, and so forth should be included in the analysis. Hence you would do a Cost-Benefit analysis, that is, the benefits outweigh the additional costs of a nicer car.

**In either situation, you need to be At The Table to be able to influence what is included.**

### TAKE HOME POINTS

- As an anesthesiologist, you can no longer ignore the pressure of cost control that the

hospital must respond to in order to succeed.

- Know the difference between fixed, variable, direct, indirect, total, average, and marginal costs.
- Remember, charges are not costs!
- Know what your perspective is, but understand the perspectives of the other parties at the table, and be flexible. In fact, changing perspective to a more system approach will allow the anesthesiologist to be viewed as a value-added physician rather than a costly provider.
- Without involvement and understanding of costs, you will not be able to successfully defend and advocate for improved care and decreased overall costs even if drug costs increase!

## Suggested Reading

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# Strategic Planning: Failing to Prepare Is Preparing to Fail

Naveen Mehra, MD and Asa C. Lockhart, MD MBA

A strategic plan articulates the desired direction of an entity, what must be achieved to attain that goal, and how to determine the allocation of human and financial resources required to reach that coordinated goal. Here is another way to think about it—strategy is a series of coordinated actions with a common goal, while tactics are simply individual actions that may or may not be purposeful. Sun Tzu, the great Chinese militarist, noted, "Strategy without tactic is the slowest route to victory. Tactic without strategy is the noise before defeat."

While the thought of a strategic plan for your anesthesia practice, group, or career may initially be overwhelming, it is easier to master if you break it down into a series of intuitive steps. A series of framing questions will provide a clearer focus.

) Ask yourself where you would like to go (objectives)?

) What items do you have going for and against you from both internal and external perspectives (assets and liabilities)?

) Are the things that you are thinking about consistent with your business, which begs the question, what business are you in (mission)?

) As you plan for the future, what is your preferred outcome (vision)?

) What will be the basis for your decisions, and how will you differentiate between what is best for the organization and your own self-interests (guiding principles)?

) How will you categorize the various issues into digestible bites and formulate an action plan (strategic planning process steps)?

## Individual Strategic Objectives

List your most important short-term (accomplished in 1 year), intermediate (accomplished in 2 to 3 years), and long-term (5 to 7 years) objectives for each key

building block of your future. These are big picture goals to give direction to the coming discussions. We usually have practices individually list various items and then assign them to dominant themes/groupings. Some typical anesthesia groupings would be beliefs (values, behaviors, ways of looking at outside influences), structures, hospital relationships, surgeon relationships, and group (internal) relationships. We suggest that you adopt some Meeting 101 rules at the beginning to guide any strategic planning discussion and keep meetings from becoming contentious and chaotic. Everyone who wants to speak should be able to share their thoughts in a respectful manner; avoid simultaneous discussions, filibusters, demeaning comments, or threats of veto by any person or small group.

## S–W–O–T Analysis

A traditional format of a strategic plan is the SWOT analysis: an analysis of your Strengths–Weaknesses–Opportunities–Threats.

Strengths (e.g., good leadership, robust infrastructure, visionary culture) and weaknesses (e.g., lack of internal discipline, suboptimal revenue cycle management) are internal to the group; you can have direct control over this bucket.

Opportunities (e.g., great OR utilization, rapidly growing favorable demographic) and threats (e.g., plant closing, horizontal scheduling, monopolistic payer) are external to the group; these issues impact you but you do not have the ability to change them.

So when formulating your professional strategy, the goal is to leverage, or at a minimum not compromise, your strengths and align yourself and your associates with opportunities. Weaknesses are flaws or vulnerabilities that are self-induced and needlessly compromise your group so they must be addressed in a proactive manner; threats require adaptive strategies to minimize their impact. You must be candid and self-aware, even when it hurts. Initially, there may not be consensus, so take the time to try to get as many of the players as possible on the same page since this will drive the following steps; do not let one person exert veto-power.

## Mission Statement

A mission statement defines the purpose of an organization and should answer the basic question of "What business are we in?" It should inspire and provide daily guidance when performing professional duties. It should also serve as a compass when evaluating the direction of the professional and business components of your group. It indicates why the organization exists. Some helpful questions to frame your discussion follow. What purposes define our group's business? What are my personal business objectives? What are the unique traits of our group? What unique talents do I bring to the group? Why does our practice exist? How will the group be judged in the future by our

patients? Our competitors? Our employees? An example of a mission statement is:

Our medical practice philosophy is

- To provide quality and compassionate care
- To always remember the individual patient's needs
- To ethically deal with our customers and employees
- To put quality and performance above reproach

## Vision

Vision statements are your preferred self-image of the future. While they must pass the elevator test, (short enough so that it could be articulated during an elevator ride), they are strong statements that inspire, challenge, stand the test of time, empower, and put the patient in the center. Your goal is to link other stakeholders' needs and desires with your strategy as the preferred solution. Talk about your vision for the future using metaphors and powerful language. The following questions frame its development. Where do we want to be next year? In the next 5 years? What is the spirit of the organization? What services do we want to provide? How do we differentiate ourselves from our competitors?

## Guiding Principles

Guiding principles are the values that organizations and people stand for—the fundamental principles that, along with the mission, make an organization unique. They are the litmus test that drive organizational choices and differentiate entity from personal decisions; however, personal behavior should not be in conflict with your practice values. For internal group decisions, this is particularly important so that decisions are based on your values and are agnostic of the individual. Most often, discussions of organizational values relate to ethical behavior and socially responsible decision-making.

These statements and beliefs are directional strategies that provide the focus and parameters for the more operational strategic objectives. They provide a means of determining the essential things that must be accomplished if an organization is to be effective. Some common themes include mutual respect, quality, equity, excellence, and compassion.

## Strategic Planning Process

In this step, you bring the pieces together. First, take the major objective groupings identified earlier and establish a flexible grid since you will probably be making a number of insertions! Within each grouping section, list the individual elements of either

where you would like to be on a particular item or issue on the left column; alternatively, you may identify current realities generated from your S-W-O-T Analysis. The column/row headings are sequenced as shown:

| Areas | Future Vision | Current Reality | Gaps Challenges | Action Steps | Ownership Resources | Target Date |
|---|---|---|---|---|---|---|
| Beliefs | | | | | | |
| Structures | | | | | | |
| Hospital | | | | | | |
| Surgeon | | | | | | |
| Group | | | | | | |
| Events | | | | | | |

The process flows from left to right for each issue or goal. Future Vision answers the question of "What would you like for this item to look like?" This represents your preferential end point. The next item is more difficult and requires brutal candor and introspection. Current Reality is where you are today. Gaps and Challenges identify the difference between where you are and where you would like to be; it is the problem that must be improved or corrected. The Action Steps identify the high level and fine detail that must be taken to address the Gaps. Based on their key competencies, an individual or workgroup is assigned Ownership of that step and the necessary Resources are identified. A realistic Target Date is determined for updates and completion. Once the item is successfully addressed, a control loop should be undertaken to confirm that the problem has been resolved and to determine if there is now a secondary issue created by your success.

## TAKE HOME POINTS

- Strategic planning is a thoughtful process of determining your optimal goals/outcomes of where you would like to take your practice or project as guided by your Mission-Vision-Guiding Principles.
- Next, assess your realistic potential actions with a S-W-O-T Analysis.
- Finally, allocate your resources in a systematic and deliberative manner to position your practice as close as you can to your preferential vision of the future.

## Suggested Readings


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# Business Plan 101: Where You Want to Go and How You Are Going to Get There

Benjamin J. Wallisch, DO FASA and Asa C. Lockhart, MD MBA

A business plan is a forward-looking document that shares the vision of how owners, or management, plan to position and grow their company from its current state to its projected and optimized future. The complexity and length of a business plan will vary depending on the intended audience and the scope of its ambition and most will include 3- and 5-year goals. Business plans should be living documents as there will likely be changes in the environment impacting key assumptions or expectations that necessitate midstream adjustments.

Prior to starting a business plan, management stakeholders should conduct a strategic retreat (which is discussed in more detail in Chapter 291) that includes an honest assessment of the current utilization of human and financial capital. This assessment should spark the process of developing a written plan to utilize available resources to direct future growth and enhance both the profitability and stability of the enterprise. In effect, a business plan is a roadmap that helps an organization navigate in its intended direction of success. Form should follow function specific to the entity and the desired end point. For example, a business plan that includes the goal of securing funding will be different than one where the end point is focused on organic growth through maximizing market share. Additionally, the length and detail of the document is reflective of the scope of its goals.

Accordingly, a traditional business plan that seeks funding for a new business or service line may be as long as 30 or 40 pages. Whereas, if the focus is primarily to update and adjust to changing business conditions, the plan might be a much smaller and concise document which includes only basic elements of adaptive strategies aimed at very targeted goals and benchmarks. **In simplistic terms, a business plan describes where you intend to go and how you plan to get there.**

## Classical Business Plan Elements

As noted above, the following elements may or may not be included depending upon

whether the audience is external (investor or bank funding) or internal (defining, measuring, and meeting goals). A business plan for a medical practice could fall into either category. For example, one written for a medical practice consolidation would be for an external audience whereas one aimed at increasing a practice's geographic coverage or market penetration would be primarily internal. There is no gold standard or rigid prescription of how many individual sections there should be, so stylistic variations may combine groupings of information. I observed from 5 to 15 sections during my research. Therefore length and formality should simply match the audience's style and personality. Below are the six most common sections found in a modern business plan and a description of their components. Again, as you read these keep in mind that this structure is subject to the plan's scope and objectives and can be combined or separated to its needs.

## Executive Summary

The goal of this succinct summary is to provide the reader with high-level insight into why your business proposition is the preferred solution for a perceived need or gap for a targeted market, spell out key financial performance metrics and goals, and illuminate how key personnel can successfully position the practice/company to meet the need. Although the executive summary appears after the table of contents, it should be written last as it is your business plan's first impression and should follow "main point up front" principles. It should only be one page, so it must be precise yet exude strength and confidence. If yours is a new company, the focus should be on demonstrating that leadership has the key competencies to analyze the market and deliver sustainable and preferential solutions. The objective of the Executive Summary is to hook the reader into wanting more detail.

## Company Description

For external audiences who may not have subject matter expertise, the company description is a high-level description of the business. It describes aspects such as marketplace needs, ownership, location, key personnel, operational excellence, the mission statement, and how they collectively create a competitive advantage. Although some will list it as a separate section, you must create mental imagery that concisely flows and portrays the need, your vision of how your products and services can address that unmet opportunity, and how you can do it with a competitive and sustainable advantage. This is the essence and promise of your message, and must answer the fundamental question of why you should exist.

## Market Analysis

The market analysis anticipates a number of questions and demonstrates your understanding of your target market, how that fits into the industry sector and its outlook, how mitigating factors will influence your success, and how the pieces to those questions fit together in the puzzle that is your business. Who is the customer? Where are you in the life cycle (e.g., new, rapidly growing, mature, or declining market), and does your concept have a viable chance of getting to full stride and profitability relative to the life cycle? How large is the target market? What potential and essential market penetration is attainable? What kind of market information (internal or external) is available, and what communication strategy will be employed to deliver your message?

Is this a direct to consumer model or will it require a sales force? Have you been able to define a narrow segment of the market so that you can have an optimized and focused message? What kind of pricing, margin corridors, and supply assumptions will you be making? Are there regulatory, compliance, trade secret, nondisclosure, or noncompete considerations?

Part of this section is qualitative and part of it quantitative. You should include only the conclusions of any studies or data sets in this section (actual source data belongs in the appendix). The answers to these questions will drive the marketing and sales plan. The reader will want to know what metrics, key personnel, and timelines will gauge success since great plans are worthless if they are not successfully implemented.

## Organization and Management

Organization and management describes the organizational structure and profiles of the management team to the external audience. It answers the questions to a number of mission critical questions. Who does what in the organization? What are their qualifications and past record of accomplishment? What are their gaps and how will you address the deficiencies? If not addressed in the Company Description, what is the legal structure, supporting infrastructure (e.g., board of directors, advisory councils), and ownership of the business? What is the plan to recruit and retain top talent? This section must answer the question of who will implement and operationalize your great concept.

## Financial Projections

Once you determine what it takes to get your concept to market, the next critical question is to determine how much it will cost so that you can make financial projections. You will need to determine the amount and timing of financial resources that will be required. If there are historical data, review the last 3 to 5 years of financial statements (balance sheet, statement of revenues and expenses, and cash flow statements) as well as potential collateral if there is a funding request.

Next, you will evaluate the prospective financial data with sales forecasts, anticipated timing of staffing and overhead costs, and financial statement projections for the next 3 to 5 years. The reader will be looking for inconsistencies between the funding and the projections. You should address contingencies head on by identifying items at risk for going wrong and how you would handle them. You may place summary statements or graphs in this section and the source data in the appendix. Remember, readability is a key attribute. As stated above, business plans are living documents that will need to be updated and used as an important management tool to demonstrate a grasp on key issues for both internal and external stakeholders.

The Suggested Readings will be valuable for the reader who may want more detail or documentation. It may include source data detail, resumes of key players, financial statements, and other proprietary data. As such, you may want this as a separate, but easily accessible, document since not all readers will have a need to know.

## TAKE HOME POINTS

- When developing a business plan, you need to keep the audience and their perspective in mind.
- You should develop a work product that is concise, deceptively simple, appropriate in length and detail for the intended audience, has an appealing readability (e.g., font size of 11 or 12, font type), and leverages visual imagery.
- Simply put, you must instill confidence that you have identified a need, an implementable solution, and you have, or will obtain, the human and financial capital that is necessary to meet definable and realistic goals that are sustainable and viable.
- If you can do this, you have identified the essential waypoints on your business' roadmap to success!

## Suggested Readings


1. http://www.sba.gov/writing-business-plan
2. http://www.entrepreneur.com/article/78610
3. http://www.myownbusiness.org/s2/#1
4. http://articles.bplans.com/writing-a-business-plan/what-is-a-business-plan
5. http://managementhelp.org/businessplanning/

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# Avoid Being Labeled "Simply a Gas-Passer": An Overview of the Perioperative Surgical Home

Navid Alem, MD, Maxime Cannesson, MD PhD, Fiyinfoluwa Ani, MD MBA, and Zeev N. Kain, MD MBA

Anesthesiology residency is not just focused on learning how to give care in the operating room (OR). In this modern era, anesthesiology training provides the education to take care of the patient throughout the perioperative or periprocedure period. That is, anesthesiologists are not "simply Gas-Passers" but are perioperative physician specialists.

The current economic reality is that the both the care system and payment continuum of care—from before the procedure, the procedure, and then after the procedure. In this type of system, it makes logical sense to have the anesthesiologists, who are the perioperative physician specialists, to emerge as the leaders of the patient's care—namely as part of the Perioperative Surgical Home (PSH).

Many anesthesiologists have been anxious about the potential change in practice model, but as you will see below you already do parts, if not most, of the PSH components.

## What Is the Perioperative Surgical Home?

The "PSH Care Model" is an innovative model that is a patient-centered, physician-led multidisciplinary, and team-based system of coordinated care. Via personalized and evidence-based care plans, it guides the patient through the entire surgical (or procedural) experience and continuum from decision for the need for surgery to discharge from a medical facility and beyond. While autonomy for both the patient and practitioner is not hindered, ambiguity is clarified and addressed, fostering a forum for improved outcomes as defined by numerous metrics. The PSH model increases patient satisfaction, while reducing costs, complications, recovery times, and length of stay in the hospital. This perioperative care model–that refers to the period before, during, and after surgery–spans the patient's entire surgical experience, starting with the decision to have surgery through 30 to 90 days after hospital discharge. The Care Pathway is

mapped out by the medical professionals from the surgeons to the anesthesiologists to the nurses to the medical device specialists to the rehabilitation therapists, such that there is complete continuity of care as well as standardization of practices to enhance patient safety.

This innovative model that has catapulted the anesthesiologist as the prime liaison for the surgical patient is understandably becoming popular among patients, surgeons, and hospital administrators. **The PSH is an endeavor that not only offers resolution to the present conundrum of who is in charge of the perioperative period, but also additionally reinforces the imperative worth of an anesthesiologist who is adept beyond the constraints of the operating room.** The American Society of Anesthesiologist (ASA) has committed the PSH model of care and stated in 2014, "Each patient will receive the right care, at the right place and the right time." Moreover, the goals of the PSH perfectly align with Berwick's triple aim of: (1) an improvement of the individual experience of care, (2) an improvement of the health of the population, and (3) reduced per capita costs of care for surgical patients.

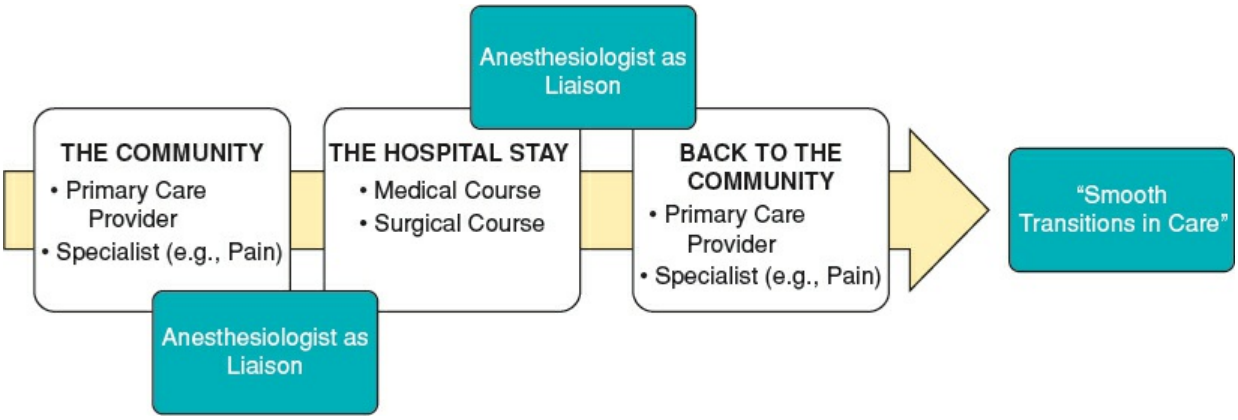


**Figure 293.1.** Care transitions: The anesthesiologist leading the way. (Reprinted with permission from Kain ZK, Vakharia S, Garson L, et al. The perioperative surgical home as a future perioperative practice mode. Anesth Analg. 2014;118(5):1127. Copyright © 2014 International Anesthesia Research Society.)

## Components of the PSH

A chief principle of the PSH is to address the entire perioperative episode as a single congruent continuum of care, rather than discrete silos of a preoperative, intraoperative, and postoperative episode that are not connected (Fig. 293.1). Remaining interlinked, the perioperative period could generally be divided into the following phases:

) Preoperative (Decision for surgery → Day of Surgery): Complete care coordination including preoperative evaluation, medical optimization prior to surgery, and early commencement of arrangements for patient discharge. As a basic introduction, this phase endeavors to use skills the anesthesiologist inherently has to decrease

variability in care and to implement preoperative risk reduction and optimization strategies (e.g., optimal anemia correction, carbohydrate loading, statin, beta-blockers, or antiplatelet management). Moreover, the anesthesiologist is the patient's liaison and succinctly coordinates the transitions of care as outlined below:

) Intraoperative (Day of Surgery → Discharge from PACU): As a basic introduction, utilizes evidence-based clinical protocols in order to minimize the variability of care and outcomes that exist between providers providing anesthesia for the same surgical procedure. The pathways adhere to SCIP protocols such as antibiotic administration, normothermia, and VTE prophylaxis and decorate in key opportunities for enhanced patient outcomes such as goal-directed therapy, transfusion endpoints, and pathways for innovative pain and nausea prophylaxis techniques.

) Postoperative (PACU → Discharge from Hospital and Beyond): As a basic introduction, a surgeon's primary resource for the diagnosis and treatment of postoperative acute events, such as pneumonia, venous thromboembolism, acute myocardial infarction, decompensated heart failure, and wound infection. Also the care coordinator for recovery including ambulation guidelines, pain control pathways, nausea/vomit pathways, physical and occupational therapy arrangement, and "readiness for discharge assessment." Potential expanding opportunities include assistance with ensuring safe discharge practices and arranging durable medical equipment when patients are discharged home, acute rehabilitation, or skilled nursing homes.

## Principles of the PSH

The PSH model will vary from institution to institution as it adapts to the culture, infrastructures, and resources available. However, universal principles include:

) **Coordinated care and integrated information technology:** Uniform EMR within the same Hospital, Seamless Transitions in Care where nothing is "lost in the system" and overlooked or repeated. Discharge Summaries are "married" to the patient.

) **Quality improvement, transparency, and patient safety:** Performance measures of outcomes as we are approaching an era in medicine in which reimbursements will be based on outcomes and there will be penalties or reduced reimbursement for hospitals for cases with complications or readmissions.

) **Patient Satisfaction:** This is rapidly becoming a key performance measure of hospital systems that is also tied to reimbursement. Above all, this is the focus of the patient-centered model. Patient satisfaction holistically includes everything from their comfort level at the facilities and with staff, to pain management, and mundane issues

such as what kind of food a patient ate and when.

- **Evidence-based medicine clinical pathways as a Means for cost reduction:** While maintaining physician autonomy to deviate from pathways when appropriate, pathways aim to provide standardized clinical protocols as a means to reduce variability in care.

- **Patient education:** Multimodal and diversified ways of elucidating recovery plans and empowering patients to play an active role in self-education is primarily important.

## Why Anesthesiologists?

The nature of training an anesthesiologist receives positions them as natural candidates to become the leaders of the perioperative environment. Starting from medical school, and extending to training and beyond, there is a diversified and proficient foundation of skills ready to materialize in the correct setting. The preparation we inherently have is unique and extensive, it transcends beyond the Operating Room into all aspects of perioperative care. Are we not experts in preoperative evaluation, postoperative and critical care, and also in pain management of the surgical patient? As a perioperative specialist, we have already acquired an innate ability to seamlessly recognize physiologic deterioration in patients, especially in those with significant comorbidities. Moreover, we are fundamentally "comforters" as we routinely triumph in the opportunity to appease anxiety and alleviate pain and suffering. By what force have we arbitrarily constrained our profession to using this skill set on only at the immediate time of surgery? We are already leaders in the operating room, now is the calling for us to be the perioperative specialist that "quarterbacks" all aspects of the perioperative continuum.

## Who Benefits From the PSH?

**The Patients**

Improved care coordination, improved clinical outcomes including less pain and suffering, focused point-of-care examinations, enhanced patient education, and increased transparency allowing shared decision making includes just some of the key principles of the PSH that the patient will benefit from.

**The Anesthesiologist**

The PSH will essentially enable anesthesiologists to maintain an indispensable utility in the current dynamic landscape. The best way to predict the future of anesthesia is to create it.

**The Surgeons**

Happy patients mean happy surgeons. The camaraderie between a surgeon and an anesthesiologist can extend beyond the OR.

**The Organization**

It all comes down to money, patient satisfaction, and enhanced outcomes. With the PSH, key principles such as reducing surgical morbidity and mortality and reducing overall cost and readmission rates are specifically addressed.

## Implementation Challenges

Indeed, human nature is to be stagnant and to remain in the comforts of routine until obligated to change. An early obstacle is getting a hospital's stakeholders to understand the need for the PSH and obtaining their buy-in. This challenge will continue to be the biggest one because a fundamental culture change of what an anesthesiologist can offer is required.

**Will the PSH be faced with push back from internists or hospitalists trying to adapt to the changing healthcare landscape?**

Yes, it is possible. However, it is important to note that anesthesiologists have a unique advantage in that they have an extensive understanding of perioperative physiology and an experience in the OR that make them the ideal specialist for the PSH.

**Will the PSH make the surgical process factory-like and eliminate patient individuality?**

No. The standardized clinical pathways the PSH promotes are for particular patient populations without contraindications; thus there will be individualized treatments or deviation from some of the pathways for patients with unique presentation. In addition, the PSH is aiming to reduce system caused variability and issues since they account for most of the complications seen in patients post anesthesia or surgery.

## TAKE HOME POINTS

- The Perioperative Surgical Home is a patient care model that is informed by the concept of the care of the surgical or procedure patient as a continuum, rather than individual silos.
- Anesthesiologists are uniquely positioned and educated to help coordinate care throughout the perioperative period. This does not mean a zero-sum arrangement, wherein the anesthesiologists start picking up the patient-care duties of other specialties as those providers drop those aspects of patient care. Rather, the goal of PSH is to create a paradigm of additional oversight and coordination of the seamless continuum of care throughout the entire perioperative period.

The goal of this chapter is to provide with an overview of a new concept of organizing care of the surgical patient into a coordinated process rather than separate interventional steps. For further information on the Perioperative Surgical Home, we have included further reading references to get you started. Garson et al. (2014) describes in detail one example of PSH applied to orthopedic patients.

## Suggested Readings


American Society of Anesthesiologists (ASA). The Perioperative Surgical Home (PSH), 2014. https://www.asahq.org/For-Members/Perioperative-Surgical-Home.aspx

Garson L, Schwarzkopf R, Vakharia S, et al. Implementation of a total joint replacement-focused perioperative surgical home: a management case report. Anesth Analg. 2014;118:1081–1089.

Kain ZK, Vakharia S, Garson L, et al. The perioperative surgical home as a future perioperative practice mode. Anesth Analg. 2014;118:1126–1130.

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# The Curriculum Vitae: Know Your Audience

Antolin S. Flores, MD

Residency training is no easy task. Filled with long days and nights spent caring for patients, giving brief presentations, and performing research—residency can cause you to get lost in the sheer grind. Before you know it residency's end nears and you must seek gainful employment. However, there is one crucial document you should have created in medical school and continued to update along the way—your curriculum vitae (CV). If you have been diligent and kept your CV updated periodically through residency then this chapter should be a brief refresher. If that is not the case, do not worry, the next few pages will provide you with guidelines and links to get you started.

Your CV is one of the key documents that will help prospective groups and departments evaluate you. If you desire to stay in academics, it will be a key document to aid in your promotion. In general, for academics a lengthy CV is the norm, but in preparing your CV for a private practice position keep it condensed to two pages in length. Therefore, it is best to know your audience! You should view your CV as your "marketing tool." (See Chapter 288—Marketing 101.)

There are numerous formats for a CV, but there is a consensus among physicians that a CV should be **clear**, **consistent**, and **organized**.

One perennial question is whether your CV should be in **chronologic or reverse chronologic order.** Each format has its advantages. Reverse chronologic mimics the format of PubMed. However, the reverse chronologic format can be burdensome to maintain for the owner of the CV and difficult to read for the reviewer. We are used to reading and assessing a chronologic history from earliest to most recent and that's what a CV is, of course, your professional history. The reverse chronologic format has its advocates but we conducted an informal survey and found that most of the leadership in our field structures his or her CV in chronologic order, so that's what we recommend to start with. But we must state that there are definitely leaders in our anesthesia community (such as the editor of this Professional Practice section) who prefer to see, at first glance, what an applicant is doing at present, as opposed to what they were up to in the 1990s.

The links provided in the references provide samples to serve as a springboard, but

you should take the template and transform it into your own style. While maintaining a professional format, personalizing your CV can give attention to your most outstanding achievements. Your CV should be in a traditional font such as Times New Roman with 10 to 12 pt font. There are several important headings/categories which will organize your information. Also there should be no gaps and all time should be accounted for in the CV. Some resources will call for the dates to be placed on the left margin where others will suggest the right margin. My suggestion is to pick the style that best suits your CV and be consistent. One caveat occurs if you are submitting your CV to an academic institution that has a standard CV format that you can find online. In that case, consider rearranging the format to something that loosely approximates that style, since that is what the executives in that department will be used to reading—remember, know your audience (Table 294.1)!

The physician's CV should have several important headings (listed in suggested order of appearance).

) **Personal/Contact Information**

This heading should contain information about you as a person including your full name, contact address, and email. You may state your citizenship/birthplace and spouse and/or children in this area as well. This allows, at the very least, for correspondence.

**Table 294.1 ■ Guidelines for CV Layout**

- Pick a template that suits you and then make it your own.
- Know your audience: private practice vs. academic.
- Clear, consistent, and organized.
- Include only activities from medical school to current, unless there is something significant. Military service, the Olympics, and Eagle Scout are significant.
- Events in each heading—start with chronologic order, modify to reverse chronologic if that is standard format at your intended institution.
- Traditional font.
- Use **bold** italics only to point out significant accomplishments.
- Any information mentioned in CV is "fair game" for employers.

) **Education**

Your medical school, undergraduate, and any additional degrees you have earned

should be listed in this category in reverse chronologic order. Some formats place a magna cum laude honor under your undergraduate heading whereas others place it under the Honors/Awards header. The final choice is up to you, just remember to be consistent.

) **Postgraduate Training**
The location, name, and title of your internship, residency, and fellowship should be listed. If you spent time in a research fellowship it may be listed here also.

) **Faculty/Hospital Appointments**
If you spent time on staff as a faculty after your training (i.e., Instructor in Anesthesiology), it should be placed here. Any hospitals in which you held an appointment or practice privileges can also be listed in this section. If you seeking an academic position or have held numerous hospital appointments you may consider separating this into two headings.

) **Certifications/Licensures**
Board certification (including board-eligible status) in any medical specialties should be placed in this section as well as state licensures. Basic life support (BLS), advanced cardiac life support (ACLS), and any other certifications should be listed.

) **Administrative/Leadership Positions**
Many residents will have little to place in this section unless you had a significant former career before entering into anesthesiology. An academic anesthesiologist will likely have listings in this heading. If you do not have many listings you should consider combining this section with the next section "Committee Service" as many of these titles will be held in conjunction with service on a committee.

) **Committee Service**
Service to any committees whether at your institution or on a national level should be listed here. Examples of these are membership on the admissions committee at your residency program (local) or Ohio Society of Anesthesiology, committee for resident recruitment (regional). A distinction should be made for service in local, regional, or national committees.

) **Professional Societies**
Membership to the American Society of Anesthesiology (ASA) and any subspecialty societies is best placed in this category. Also listing any general medicine societies such as American Medical Association (AMA) is appropriate.

) **Honors/Awards**

In this section, you should list any honors such as Alpha Omega Alpha or Resident of the Year received in medical school and thereafter. Unless a very significant honor was obtained prior to medical school, routine high school and college honors should be not listed. Also if you served as a Chief Resident it is best placed under this heading.

0) **Educational Activities/Lectures**

As a resident or fellow you likely gave a number of lectures or Grand Rounds presentations. If you gave presentations to the medical students you should place them under this heading.

1) **Research Abstracts/Publications**

Any poster presentations at a research meeting as well as peer-reviewed journal publications in which you were involved are best placed in this category. If you were an active researcher or are seeking an academic position it is best to separate these two sections to allow for distinction of peer-reviewed work.

2) **Interests/Skills**

Under this heading you will want to place any additional language or programming skills you possess. You should list a few activities you enjoy outside of work such as bicycling, cooking, or traveling. This allows further personalization and is an area that is especially important for private practice groups who seek well-rounded candidates. If you are an Eagle Scout, do not fail to list this on your CV in this section, as this Scouting rank stays with you for life.

Many anesthesiology residents have active community involvement. If significant time has been spent in activities within your community, you may consider adding this heading. However, if you volunteer at a local soup kitchen or assist in building homes infrequently then consider placing it under interests.

If you are a veteran or serving in a reserve capacity, this should be noted under "Other Professional."

The CV is generally created and edited in Microsoft Word, but should be converted to the Adobe PDF format when distributed electronically. This hides formatting and gives a professional appearance to your CV. Finally, once your CV is formed you should have several trusted peers review it prior to sending to prospective employers. A trusted faculty physician mentor, a resident peer, and colleague outside the field of medicine can all provide valuable insights. You should ask them to provide comments on clarity, consistency, and organization.

## TAKE HOME POINTS

- The curriculum vitae is a vital document that creates a narrative of your professional and, to some degree, personal life. When clear and organized, it will assist you in obtaining a job or promotion.
- Remember to choose a style that suits you and keep it consistent throughout. Each heading should be a timeline for the reader to follow.
- Also having someone outside of your field review it for clarity and consistency will ensure it is easy to follow.
- Once you have created a proper CV, it is simple to keep updated. Now get started!

## Suggested Readings

http://medicine.osu.edu/students/life/career_advising/pages/cv.aspx. Accessed August 31, 2014.
http://cv.hms.harvard.edu/index.php. Accessed August 31, 2014.

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# Your Career: Interviewing

Antolin S. Flores, MD

A young gentleman appears for an interview with an anesthesiology group 5 minutes after the scheduled start time at the administrator's desk. He is dressed in a tan-colored suit with a pink shirt and green polka-dot tie. Sporting an earring in one ear, he checks the time on an oversized, jewel-encrusted watch on his wrist. He appears nervous, biting his nails and rapidly texting on his smartphone, as he waits to be escorted into the interview with the group president. The secretary quietly observes his activities and relays this information to the physicians unbeknownst to the candidate.

Would you hire this candidate? The interview hasn't even begun…or has it?

You have worked hard as a resident and have been fortunate enough to obtain an interview with a highly regarded private practice anesthesiology group in town. The major question looming is: (1) how do you prepare? and (2) how do you put forth your best effort on interview day?

Regardless of the type of practice you desire to enter into after training, odds are you will have to interview in person before any final decisions are made on your candidacy. Many practices, private and academic, still heavily rely on the interview of potential candidates due to the commitment they are making in hiring a clinician to join their group. Joining an anesthesiology group has been compared to a marriage. The interview is a very important step in this courtship, except that in the first formal interview you should prepare is if you not are courting your intended but the family as well! Many groups use the interview and the courtship process to ensure that the potential employment of a candidate is long-term by doing their due diligence in exploring whether he/she will fit well into personality and practices of the group. Hiring a new physician occupies resources and thus it is in their best interest to have a long-term commitment—"marriages not affairs." In addition, it enables the candidate to get a closer inspection of the group, their makeup, and the setting(s) in which they might practice. Every institution and practice has a culture. It is up to you to understand how you might fit in within the group.

## Preparing for a New Job: The Network and Your

## Curriculum Vitae

Always remember that our professional network is smaller than you think. Anybody who will be interviewing you has already likely obtained the background information about you they want inside of three phone calls, regardless of who wrote your introductory and reference letters. **The members of the practice will just call the people they already know, so you should accept that fact of life.** The network also works the other way, of course, and will also allow you to make (discreet!) inquiries as well.

As noted in Chapter 294, your curriculum vitae (CV) must be absolutely professional and letter-perfect, not even one tiny mistake or typo. Concentrate on your professional accomplishments, without bragging, inflating, or exaggerating. If you are a resident, you might want to consider noting what your residency project was or the talks and grand rounds you helped to present. Include just enough personal and "outside" information to allow the interviewers to connect with you and spark easy casual conversation during lunch or dinner or other "down time" during the interview day.

**Table 295.1 ■ Commonly Asked Questions at Interviews**

1) Why this particular area/region? Is there a family connection?
2) Why private practice/academic anesthesiology?
3) What are your strengths/weaknesses?
4) What are your areas of interest and/or skills in anesthesia?
5) What are your goals 5 years from now? 10 years? Career?
6) How would others describe you?
7) Tell me how you handled a stressful/difficult situation?
8) Why should we hire you?
9) What are your outlets for stress?
10) Tell me about your hobbies?

## Preparing for the Interview

Your diligent job search through networking with residency alumni, faculty contacts, or "cold-calling" area groups coupled with your well-prepared CV likely secured an interview. Now it is up to you to put forth your best effort in informing the group who you are in person. In the time leading up to the interview you should review and become familiar with every aspect of your CV. Many interviewers will skim through your CV and focus on one or two areas, choosing to find out more about you based on those few

areas. You will likely have a number of interviewers and thus many areas of your CV may be covered.

You should consider practice interviews both with your peers and faculty. This will simulate conditions of the actual interview and allow you to hone your answers of many commonly asked questions (Table 295.1). You may even want to develop more possible questions particular to the practice you are interviewing with. Practicing will leave you more comfortable and relaxed, allowing you to be yourself on "game day."

With the rise in popularity of the Internet and social media accounts, knowingly or unknowingly, much information is available on an individual. It is highly recommended before your interview to review the information available publicly about you on social media sites (e.g., Facebook, Twitter, and so forth) and on the internet. If there is any questionable content it should be removed, as this can be viewed as unprofessional and ultimately disqualify you as a candidate. A common suggestion has been to "Google" yourself periodically as information you may not even consider could be available. For example, organized event participation (marathon, triathlon) or involvement with political organizations is often publicly available through a simple search.

On the contrary, there is often a wealth of information on the internet regarding the hospital and practice that is publicly available. Prior to interview day, you should research information such as the size of hospital and types of surgical procedures performed. Also information on the anesthesiology group, its members, and their scope of practice, oftentimes, can be found. If you were connected to the group by a faculty member or alumni, contact them and inquire further to learn more about the practice. Spending some time learning some basic information will demonstrate interest to the group and will assist in generating questions you will want ask.

## Interview Day—Your Best Effort

The impression made in the first few minutes of the interview is often the longest-lasting. As such, you should pay attention to detail in your personal hygiene and clothing for interview day. It is often best to keep your look simple, professional, and conservative in choosing attire, jewelry, and hairstyle. You may normally enjoy brightly colored clothing and flashy accessories but during an interview they will only serve as distractions at a time when you want your personality to speak loudest. The geography of the hospital or practice may be casual but being a physician is a professional job and you should dress, at least for the interview, as if you understand that. The smartphone, as an accessory, has become a staple for the modern physician but can be a distraction. It is recommended you silence the ringtone and minimize the use of it throughout your interview day as frequent use of it can be viewed unfavorably.

The interview is now upon you and you should check and recheck your itinerary in

the days leading up to your interview in order to be timely. A confirmation email or phone call to the group in the days prior will demonstrate genuine interest. Of course, you don't want to show up 30 minutes early but you should **never** be late. If you need to use public transportation on the day, plan accordingly. In general, showing up 5 to 10 minutes early is acceptable.

It is important to recognize that while the final decision does not rest in the hands of the administrative staff, unpleasant interactions with them will be relayed to the physicians that do. You should make every effort to be courteous to everyone you meet during the interview time. Also recognize that while you are waiting for the interview they may be watching you and it is best to remain professional at all times during the day.

## The Interview

Since you have researched the group and hospital and reviewed your CV, the interview should be a breeze right? There are a few pieces of advice that can help you best display yourself.

During the interview, you should be ready to discuss yourself and your professional goals. Attempt to focus on your positive attributes and maintain a positive attitude. You have worked hard to put yourself in this position now you can "sell" yourself. Be honest and be yourself. Of course, at some point you may be asked about weaknesses but you want to emphasize your strengths, qualifications, and skills. Don't be arrogant but don't beat yourself up either. Talk about what you as a unique individual can bring to the group. It is also best not to speak negatively, if asked, about former employers as it can reflect negatively on you.

You will likely meet a number of group members and have many interviews over the day. It is important not to get discouraged if you had a particularly tough interview or felt you didn't put your best self forward on one. There are many personalities in a group and you may not click with every single one. In fact, some groups ask one or more members to play the role of skeptic and ask a few tough questions. Stay positive.

It is very important to ask questions throughout the day and in every interview. Prepare a list either on paper or in your mind so that any openings for questions are filled. This demonstrates curiosity and interest in the group and allows for the members to "sell" the group to you. You also want to ask the right questions to the right people. It is probably better to ask a junior member about the call schedule than the group president. Likewise, regarding finances it is acceptable to inquire about salary and finances in the interview but don't dwell on it or bring up in the beginning.

## The Followup

After the interview concludes, always send a thank-you note or professional letter of gratitude to every member of the group you spoke with. You might even include any administrative personnel whom you had significant contact with. This displays a high level of professional courtesy and is another step in the courtship process.

## Final Note

You may have the opportunity to bring your significant other to a part of the interview such as a dinner or luncheon. This is a good idea to take advantage of bringing them along. He/she is a significant part of your life and involving them in the final decision will lead to satisfaction in the transition to a new group and stability in your career. It is in the best interest of the group and candidate to be a good fit as the result will be a mutually agreeable long-term relationship. Please find Table 295.2 below which contains a checklist of the important pearls for a successful interview. All the best!

**Table 295.2 ■ Interview Pearls**

- Know your CV and social media/internet presence
- Research the hospital and practice interviewing
- Be timely
- Professional attire
- Maintain a professional attitude
- Relax and be yourself
- Prepare and ask questions
- Don't dwell on finance aspects, but don't avoid them
- Always send a thank-you or followup note

## TAKE HOME POINTS

- Don't get rattled—if you are feeling overwhelmed, try to keep in mind that the purpose of the first interview is, in some ways, to get to the second interview.
- If you are interviewing out of town, read up a bit on the area so that you can initiate casual conversation and take some of the load off the interviewers to entertain you at dinner. For example, the editors have a colleague who once interviewed for a job in Cooperstown, NY and managed to delay all baseball talk until the evening dinner interview.
- Don't ever lie or embellish in an interview, you will be found out, if you aren't

already.

- If you are asked about any negatives in your background, be brief, honest, and forthright without placing blame on anybody. State briefly and clearly what happened and what you learned from the experience that will prevent it from happening again.
- When asked about your personal negatives or your weakest points, DON'T get cute! Tell the truth. If you found that you did not have an inborn affinity to neuroanesthesia, say so, and then describe what you did in response to that, such as doing extra rotations in neuroanesthesia, attending extra lectures, and so forth.
- Don't run the surgeons down.

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# Your Career: Understanding the Basics of Ownership Jobs

Erica Stein, MD

## Introduction

In the current anesthesiology job market, there are many different types of practice models that an anesthesiologist may join, with one such being an "ownership practice." The goal of this chapter is to provide a basic outline of common elements of ownership practices. Please note that an anesthesia group's practice can be extremely variable and this chapter is only meant to provide an overview.

## Different Types of Partnership Tracks

One of the common anesthesia practice arrangements in private practice is the formation of an anesthesia group. The anesthesia group will have an exclusive contract with a hospital or ambulatory care center (ACC) to provide anesthesia services. Therefore, in order to participate in the practice of anesthesiology at any of these locations, an anesthesiologist must be a member of the anesthesia group that is contracted. Many anesthesia groups not only employ anesthesiologists, but also nurse anesthetists (CRNAs) and anesthesiologist assistants (AAs). Anesthesia groups are generally structured as "ownership groups" and "nonownership" or "employee" practices. When interviewing with a group, it is extremely important to identify what type of practice the group employs and what type of position you are interviewing for. For example, some traditional ownership practices might be only interviewing candidates as employees. Thus, the type of position available needs to be clarified prior to the interview.

For ownership practices, the term "partner" is commonly used; however, the word "partner" can have many different meanings. An equity partner is generally what many people think of when the term partner is used. An equity partner is part owner of a business (i.e., the anesthesia group practice) and is entitled to a portion of the distributable profits and owns a share of the business. It is important to note that the percent ownership may be varied among equity partners and potential equity partners

should be aware of the group's practice regarding shareholder status. This is important as the percent shares owned by an equity partner may influence his/her ability to vote as a member of the group. See Table 296.1 for definitions of various types of ownership.

Another commonly used term by anesthesia group practices is a "salaried partner." It is important to understand that a salaried partner is paid a salary but does not have any fundamental ownership in the practice and, therefore, will not be allowed to vote on matters related to the group's practice or finances. Salaried partners may receive incentives or bonuses for clinical performance, but a salaried partner is not entitled to any portion of the distributable profits. The difference between an equity and salaried partner are important distinctions that need to be made – do not fall into the "partner" trap, as not all "partners" are equal.

## The Buy-In

In general, to become an equity partner, there has traditionally been some type of "buy-in." Buy-in structures vary from practice to practice and are the process in which an employee becomes an equity partner. An outline of the partnership track should be provided in the employment agreement and provides each party (employer and employee) with a basic understanding of when the opportunity to become an equity partner will become available and the key aspects of the partnership. At minimum, the employment agreement should indicate a time period that an employee must work for the group to become considered for partnership. If the terms of the buy-in were not spelled out in the employment agreement, the terms can be negotiated when the physician is eligible to become an equity partner. It is not uncommon for both parties to reserve the right as to whether the buy-in agreement will be executed. Remember, most established anesthesia groups with equity partnership tracks are looking for "long-term relationships" and the current equity partners need to insure that you are a good fit for the group, not only in terms of clinical care, but also work ethic and personality. If the group decides not to execute the buy-in agreement, provisions should be outlined in the contract as what happens to the employee—is he/she terminated? Can the individual continue working for the group as an employee? How does this impact any benefits (retirement, professional liability coverage, etc.) that the individual has been receiving?

**Table 296.1 ■ Types of Ownership**

| Type of Ownership | Definition |
|---|---|
| Equal ownership | All partners own equal shares of the corporation |

| | |
|---|---|
| Partial ownership | A new partner will be offered a partial or minority ownership position in the corporation. This allows the current group ownership to have a majority position in the practice while still allowing the new hire to have the security of an ownership position |
| Incremental ownership | Limited shares are offered initially. Then, over a specified period of time, additional shares can be obtained or purchased |

## Buy-In Example

Dr. X, a new anesthesia graduate, joins the fictitious "Best Anesthesiologists Group of America." He agrees to be paid a percentage of his collections for the first 2 years of employment; then, at the end of the 2 years, all of the group's equity partners will vote to determine if he will be offered the opportunity to become an equity partner. Do not be fooled, even though this situation might not be labeled as a "buy-in" by the anesthesia group, many groups refer to the time period before becoming an equity partner as a "junior partner." The difference between Dr. X's "full salary" as an equity partner and his salary during the first 2 years of employment is his buy-in.

## Buy-In Negotiations

It is important to remember that the terms of the buy-in may be subject to negotiation upon hire. For example, if Dr. X is not a new graduate, and, instead, has been in practice for 5 years, if he applies for a position with the "Best Anesthesiologists Group of America" he might be able to negotiate the time period to become partner to 1 year, as he already has learned to practice as an attending anesthesiologist and might not need the grooming that new graduates require. In addition, Dr. X may be able to give the anesthesia group a lump sum of money to decrease the length of time until he can be considered to be an equity partner. Buy-in provisions are generally not negotiable for new hires, as new employees are generally considered to be less valuable. Remember that a physician who has been in practice has more clinical and practice management experience, and may have been exposed to more leadership roles. In addition, senior partners within a group possess longstanding relationships with the hospital's administrators and other physicians.

## Becoming an Equity Partner

When a group employee becomes an equity partner, this change in status will generally be accompanied by an increase in income, status, and responsibility within the group. It

is important to discuss with the group what changes in responsibility will occur. Some questions to consider about becoming an equity partner:

- Does the group have a Board of Directors and what is its role?
- How are equity partners elected to the Board of Directors?
- Do all equity partners participate in the group's business matters?
- Are the shares of ownership in the group equal among all equity partners? If not, how is share distribution determined?
- What are the nonclinical expectations of becoming an equity partner?
- Is there extra pay for participating in managing issues related to the group's finances and hospital/ambulatory care center relationships? (Some groups call this "leadership pay").
- How are profits distributed to the equity partners?
- Are there additional retirement benefits extended to the equity partners?

Some benefits of being an equity partner include being active in managing both the group's finances and business matters. As an equity partner, you may be directly involved in negotiating anesthesia services, and their expansion, with the facilities that your group contracts with. This would be clinical work that directly impacts you. For example, the hospital may want your group to cover another facility or provide additional operating room coverage after-hours; as an equity partner, you can be involved in these discussions to come up with an arrangement that is most mutually beneficially. Also, equity partners will determine hiring decisions—will the group be expanding hiring physicians? Will the group be changing its practice model and hiring more CRNAs and AAs? What will be the group's practice model in terms of medical direction and supervision? These are all issues in which an equity partner can exert influence since he/she is a shareholder in the business. Equity partners also determine issues related to benefits provided by the group such as eligibility, coverage, and the carrier. This includes health insurance, professional liability insurance, and retirement benefits. There is a lot of responsibility that can come with being an equity partner and it should be remembered that many groups do not pay the equity partners for time spent overseeing nonclinical matters. However, if you seek a high degree of autonomy in your practice, becoming an equity partner would likely be a good fit. A summary of the advantages and disadvantages of becoming an equity partner are found in Table 296.2.

## The Buy-Out

In addition, one must be familiar with what happens if an equity partner leaves a practice. If an equity partner leaves a practice, he/she may be entitled to a payout, otherwise known as a "buy-out." Among anesthesia groups, this practice is becoming less common, but when assessing an anesthesia group, this should be considered. An

equity partner can be eligible for a buy-out if he/she is relocating, becomes disabled, or dies. This is generally paid as deferred compensation over a time period. The time period can be variable so as to not overburden the corporation (financial implications) or the individual (tax consequences). Buy-out arrangements should provide for unforeseen contingencies such as a reduction in the practices' income or increase in future expenses and should also permit for renegotiation by either party. Since there can be tax implications to both buy-outs and buy-ins, it is recommended that a tax accountant is consulted.

**Table 296.2 ■ Advantages and Disadvantages to Being an Equity Partner**

| Advantages | Disadvantages |
|---|---|
| Having a voice in the group's business and financial matters (i.e., benefits planning, salary determinations) | Having to spend "nonpaid" time on the group's financial and business matters |
| Having a voice in the group's clinical responsibilities (i.e., expansion of anesthesia services or practice model) | Having to spend "nonpaid" time on the group's financial and business matters |
| Having the ability to directly speak with hospitals and ambulatory care centers about the anesthesia services provided (i.e., handle compliments and complaints about anesthesia providers) | Having to deal directly with hospitals and ambulatory care centers about the anesthesia services provided (i.e., handle compliments and complaints about anesthesia providers) |
| Having increased security that comes with owning a share of the practice | Having more responsibility than just practicing clinically |

## TAKE HOME POINTS

- Make sure you understand whether the practice you are looking at is an ownership group.

- Understand precisely what the group means when the term "partner" is used.
- An equity partner is part owner of the anesthesia group and is entitled to a portion of the distributable profits and owns a share of the business. Equity partners typically enjoy an increase in compensation and benefits.
- A salaried partner will be paid a salary but will not have voting powers in the group's business decisions.
- Make sure you understand the precise nature of the buy-in. This can be via a salary differential for several years, or less frequently, a paid lump sum.
- Nothing is forever, so make sure you understand the mechanics of leaving the practice.

## Suggested Readings


American College of Physicians. Income distribution and partner buy-ins & buy-outs. Retrieved from http://www.acponline.org/running_practice/practice_management/human_resources/income_dist.pdf.

American College of Physicians. Partner buy-ins. Retrieved from http://www.acponline.org/residents_fellows/career_counseling/partner_buy.pdf.

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# Your Career: Employee Jobs

Erica Stein, MD

Anesthesiology graduates are facing more options than ever in the current anesthesiology job market in terms of what type of practice they join. As an anesthesiologist, it is becoming more common to be offered a position as an "employee" of a hospital, healthcare maintenance organization (HMO), anesthesia group practice, or practice management company. Employee positions can be found in both private practice and academic anesthesiology. Since employee practices are highly variable and can differ regionally, the goal of this chapter is to provide a basic overview of how being an employee impacts your career as an anesthesiologist. Research from surveys performed by the American Medical Association demonstrates that there has been a shift away from physician ownership of practices over the last decade. The literature demonstrates that ownership in a practice was less common among younger (<40 years old) than older physicians and women compared to men.

## Single-Specialty and Multispecialty Groups

As an employee, an anesthesiologist can be part of a single-specialty or multispecialty group. A single-specialty group is a group that employs only physicians who practice one specific type of care (i.e., anesthesiologists). Single-specialty groups are most represented by anesthesia groups that you may encounter in private practice anesthesiology. In a single-specialty group, there may be an individual or group of shareholders that control the business matters of the group, while all of the other members of the group are employees. Single-specialty groups can offer more financial security and controlled lifestyle although compensation may be productivity-based. One of the advantages of productivity-based compensation is that it encourages and rewards extra effort by individuals. However, it can create competition among group members and the patient payor mix can have negative effects. Alternatively, a single-specialty group may provide compensation equally among its employees as this discourages competition. However, this presumes that all employees are equally skilled, productive, and motivated, but high producers will have little long-term incentive.

A multispecialty group offers various types of medical specialty care. Advantages of multispecialty groups include providing multiple patient services at one location and the ability to negotiate more favorable managed care contracts. In addition, large multispecialty group practices may be able to offer generous total compensation packages such as salary, benefits, vacation, and CME time. However, the actual salary is often lower than single-specialty practices as it may reflect fewer working-hours in a multispecialty practice compared to a single-specialty practice.

## Hospital-Owned Practice

Being a hospital employee is another option for an anesthesiologist as hospital-owned practices are becoming more common. In this type of arrangement, the anesthesia group practice may be partially owned by the hospital or the hospital may own the entire practice. The advantage of this type of practice is the ability to assume more risk, more effective managed-care negotiations, and having a large referral network of physicians. Similar to large multispecialty practices, autonomy is diminished and the hospital may impose policies and procedures that individuals cannot influence. In this type of arrangement, financial incentives relating to productivity and autonomy of practice may not be available. When looking at a job as a hospital employee, you should inquire about the hospital's finances and patient-care philosophy since you will need to insure that the hospital is financially sound (unlikely to go bankrupt or acquired by another entity) and that the hospital's philosophy is in-line with your personal and professional goals in terms of patient-care. Remember that there may be other obligations as a hospital-employee—these would include hospital committee service, as well as research and teaching duties, particularly if the hospital has an academic mission. Compensation is generally a salary plus incentive. Incentive or bonus pay can be based on a myriad of factors ranging from productivity to evaluations. When being offered incentive pay, the anesthesiologist must have a full understanding as to what criteria need to be met and under what conditions the sum is paid. This type of compensation arrangement provides security for the employee but, depending on the amount of incentive pay, can discourage entrepreneurship and may support minimum-effort work standards. Also, because hospital-employees will generally be provided with benefits it i s **very important** to fully understand what benefits are included as part of your compensation package, such as healthcare, retirement, vacation, away-meeting, and other CME time.

## Healthcare Maintenance Organizations

Staffing models in HMOs can be similar to large multispecialty group practices. The practice may be partially owned by the physician employees, with these physicians

being employed by either the group owning the practice or the insurer. Generally, physicians are paid a salary and incentive is based upon productivity or healthcare resource utilization. An advantage to this arrangement is job security. This arrangement also rewards groups who deliver cost-efficient effective care and/or who are productive. Disadvantages include loss of autonomy when running the practice, as the group may have to be in compliance with rules and regulations created by other individuals within the HMO. Just as with other employee positions, it is very important to fully understand what benefits are included as these can differ significantly between HMO practices.

## Anesthesia Practice Management Companies

In recent years, anesthesia practice management companies (APMC) have become increasingly prevalent and may be either single-specialty or multispecialty groups. When single-specialty anesthesia groups are faced with increasing operating costs and decreasing payment from payors, the shareholders may decide to sell the anesthesia group practice to an anesthesia practice management company. This has led to an increase in APMCs obtaining anesthesia service contracts with hospitals and ambulatory care centers nationwide. When evaluating a job as an APMC-employee, you must understand in as close detail as possible what clinical services you will be asked to provide and at what locations. Generally, most APMCs will pay a salary and, depending on the employment agreement, there may be financial incentives offered for productivity. As with all bonuses, the anesthesiologist needs to understand the criteria required to be eligible for the bonus as well as the timeline for when the incentive is given. An advantage in working for an APMC is job security and the potential that, since APMCs are generally large corporate entities, that hold multiple anesthesia contracts, they will be able to better negotiate contracts with both facilities and payors. However, there may be significant disadvantages. Sometimes, APMCs obtain anesthesia service contracts with facilities upon the premise that they will provide the same anesthesia services, at a “lower cost.” Therefore, it is not unusual for APMCs to institute cost-cutting measures which individual practitioners are expected to carry out, yet the individual practitioner may feel a loss of autonomy as these rules and regulations came from administrators within the APMC and not the anesthesia practitioners on-site. Another disadvantage is that the APMC will dictate the care model, such as medical direction, supervision, direct provider, etc. and it is important that that your personal beliefs surrounding patient-care are articulate with those of the APMCs management. Also, APMCs typically employ their anesthesia providers on an at-will basis and there is no shortage of them terminating anesthesiologists with little or no notice.

## Summary

When considering becoming an employee of any of the afore-mentioned types of anesthesia practices, it is **very important** to understand the terms of your employment agreement. There needs to be a clear delineation of responsibilities (clinical and administrative) and the time commitment that an employee is expected to provide. Some questions to consider before accepting a job as an employee include:

- What is your job description? For example, does the word "anesthesiology" include "pain management" or "intensive care coverage?"
- How clearly are your responsibilities defined—preoperative and postoperative care, responding to Code Blue?
- Will you be caring for all types of patients—adult, pediatric, obstetric, cardiac, and thoracic? And how much trauma and at what levels?
- What is the anesthesia staffing model—anesthesia care team, supervision, solo?
- How is call scheduling determined?
- If your employer provides care at multiple facilities, how and where will you be assigned?
- How is part-time and full-time status defined?
- Does the employment agreement contain a board certification requirement?
- Will you have any autonomy over your clinical practice?
- What is the true compensation beyond simply salary? (Table 297.1)

**Table 297.1 ■ Description of Benefit Considerations**

| Benefits | Considerations |
|---|---|
| **Compensation** | Salary or amount paid for clinical ± administrative work |
| **Vacation** | How much vacation time is allowable? Is vacation time considered paid time off? What happens to any unused vacation each year (i.e., can it be rolled over to the next year?) |
| **Continuing Medical Education (CME)** | Does the employer provide time CME? Is this time paid? Does the employer provide any monetary allowance/stipend for CME-related activities? |
| **Retirement** | Determine eligibility criteria for retirement plan participation (i.e., 401(k), pension, etc.) Are there any employer-matched contributions? |

| | |
|---|---|
| **Professional Liability Insurance** | Does the employer provide professional liability insurance? What type of insurance is it (i.e., claims-made or occurrence)? What happens if your position is terminated, are you responsible for buying additional insurance (i.e., tail coverage, etc.)? |
| **Health Insurance** | Does the employer provide health insurance? Does the employer provide vision and dental insurance? |

## TAKE HOME POINTS

- Think carefully about your own strengths, weaknesses, and practice principles before seeking an employee job. You want to evaluate what you would do in a job with limitations on your practice autonomy **before** you take an employee job, not after. This is especially true if you are seeking to transition to an employee job from another type of practice situation.
- APMCs are very often for-profit companies that are sometimes publicly owned by the stockholders. Managers of these companies are therefore beholden to the stockholders, whose financial interests then compete with the anesthesia practitioner's and the patient's.
- APMCs will often buy out a number of anesthesia practices in a city. This will give the prospective employee a chance to discuss the experience with the APMC with employees at locations other than the location where the job opening is. Use that opportunity to find out as much as you can about how the parent anesthesia-management company does business. This includes not only how anesthesiologists are hired, but also how they are fired or terminated. And how the APMC interfaces with the hospital medical staff office in terms of medical staff appointments, peer reviews, and medical staff bylaws.

## Suggested Readings


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# Your Career: Understanding the Basics of Locum Tenens Jobs

Erica Stein, MD

"Locum tenens" is a Latin phrase that is used to describe a physician who temporarily practices in the place of an absent colleague. Many anesthesiologists practice as a locum tenens physician at some point during their career as way to experience another type of practice setting or make additional income. There is a myriad of opportunities to work as a locum tenens in anesthesia and this can allow the anesthesiologist to experience a variety of practice locations including urban, rural, and suburban practice. In addition, locum tenens work can permit the anesthesiologist to experience different practice settings when working for a solo practitioner, small single-specialty group, large multispecialty group, hospital-owned group, or anesthesia practice management company. The goal of this chapter is to provide a basic overview of locum tenens work for the anesthesiologist. Since locum tenens is regarded as an independent contractor, it would be prudent before starting any locum tenens work to consult with a tax accountant and an attorney familiar with anesthesiologists working in this capacity as tax and medicolegal implications can vary regionally across the United States and internationally.

## Starting the Process

Information on locum tenens opportunities is almost unlimited. However, an anesthesiologist must go through a recruitment or staffing firm as hospitals and groups almost always contract with these firms to fill open positions and it is very rare for an anesthesia provider to work directly with a hospital on a locum tenens job. Resources on recruitment firms can be found using online search engines, professional journals, on career center websites, and with some state medical societies. When choosing a recruiting firm, there are several steps that a physician should take:

- **Know your recruiter.** Just as in any relationship, both the recruiter and the anesthesiologist need to understand each other's background. A good recruiter should make an effort to learn as much about your professional and personal history as well

as your character. On the other hand, you need to ask the recruiter questions about his/her educational background and employment history and find out how many physicians he/she has placed. If you feel that the recruiter lacks the experience or ability, go with a different firm or ask to have another recruiter handle your case.

- **Speak with anesthesiologists the recruiter has placed**. By contacting other anesthesiologists who have used the recruitment firm you can find out if the firm has the ability to deliver what they promise. (Does the locum tenens opportunity match what was advertised? Does the recruitment firm pay for services in a timely manner? Is the recruiter professional?)

- **Maintain control**. A recruiter is there to facilitate the search process, and show you what locum tenens jobs are available in your specified geographic area. It is the recruiter's job to walk you through the process and answer all your questions (or at least provide you with the information of someone who can).

Before accepting a locum tenens job, it is important to consider why the hospital or facility is seeking locum tenens work. One of the **largest red-flags** can be if it is clear that no previous physician ever held the position long-term; however, there are many other practical reasons such as difficulty recruiting and retaining physicians in underserved areas which provide for a legitimate reason for locum tenens work. Other legitimate reasons for hiring locum tenens is that it gives local physicians time off for vacation, continuing medical education, maternity leave, or unexpected health-related absences. In addition, a locum tenens might be used to maintain coverage or expand anesthesia services while a permanent anesthesiologist is being recruited.

Aside from investigating why the position is available, you need to inquire as to the duration of the assignment as there can be wide variations—with some assignments lasting anywhere between one day to several months. **Medicare regulations prohibit a locum tenens physician from providing more than 60 continuous days of care.** Also, make sure you know the practice location for your assignment and understand that it might be subject to change as well. Since locum tenens assignments can require travel, it is important to determine if housing and transportation accommodations will be provided and the type/location of those accommodations.

Since locum tenens is regarded as an independent contractor, benefits are generally not provided. This means that you will have to obtain health insurance from an independent provider. If you are practicing locum tenens in a foreign country, you may have the option to purchase short-term health insurance. Remember, that as a locum tenens worker, you are only paid when you are working; therefore, there is no paid time off or sick leave. Another consideration is professional liability insurance—you must ask if the recruiting agency provides it (some do not!). In addition, you should ask if the

professional liability insurance is "claims-made" or "occurrence." An "occurrence" policy covers the clinical services provided during the time that the insurance coverage was in effect no matter when a claim relating to those services was made. On the other hand, a "claims-made" policy provides coverage for claims asserted only during the time frame that the policy was in effect, thus, once the claims-made policy expires or if coverage terminates, there is no insurance protection unless "tail" coverage is purchased. "Tail" coverage is purchased from the company that underwrote the original claims-made policy whereas "nose" coverage is purchased from a new insurer to provide retroactive liability protection from any claims that would arise after the termination of the original claims-made policy. If tail coverage is needed, it could be negotiated as part of the overall compensation for that locum tenens assignment or it would have to be purchased separately. Other benefits such as retirement and continuing medical education time and stipends are not provided when doing locum tenens. Since locum tenens work does not provide any benefits outside of professional liability (if included), monetary compensation will be slightly higher than a comparable salaried position so as to attract qualified anesthesiologists.

Another issue related to locum tenens is credentialing. When working with a recruiting firm, the firm will generally handle all matters relating to licensure as well as facility credentialing to insure that all the necessary paperwork is ready prior to the start of the assignment. Table 298.1 summarizes and describes additional questions to ask when considering a locum tenens position and was adapted from a similar table found in an article by Maniscalco, published in 2003 (see Suggested Readings, below).

In summary, working as a locum tenens can be an exciting opportunity as an anesthesiologist can gain experience in different geographic locations, both domestic and international, as well as experience different practice models. Although working within the locum tenens industry is generally temporary, it is very important to be prepared by for the assignment. Adequate preparation includes asking questions of both the individuals at the recruiting agency and the facility to learn about the position and its requirements, as well as insuring that you have the appropriate professional liability insurance and credentialing necessary for the locum tenens assignment.

**Table 298.1 ■ Questions to Ask Before Accepting a Locum Tenens Opportunity**

1) Why is the position available?
2) What are the specific responsibilities of the position (including hours expected to be worked, overtime hours, call)? What type of anesthesia

services are you expected to provide (pediatrics, obstetrics, cardiac, thoracic)? Are you expected to provide anesthesia services outside of the operating room (i.e., intensive care unit and acute/chronic pain management coverage)? What is the staffing model (medical direction, supervision, solo cases)? Will you be working with nurse anesthetists or anesthesiologist assistants?

3) What are the available resources at the facility? Are these resources available after-hours? Are other anesthesia practitioners available at all hours? What technology is available (i.e., ultrasound, fiberoptic scopes, glidescopes)?
4) What types of cases does the hospital normally do? In rural areas, how are patients transferred to tertiary care centers?
5) What happens in the case of personal illness?
6) Are accommodations provided? Does this include housing and transportation? If so, what type of accommodations are provided?
7) What type of malpractice insurance (claims-made or occurrence) is offered? Does the malpractice insurance meet minimum state standards in terms of coverage per incident?
8) Describe the credentialing process. Does the recruiting firm handle licensure and facility credentialing? Is this service included or at an additional cost?
9) Is there a termination clause in the contract in case the position is not satisfactory (for either party)?
10) Are there 24-hour risk management services available? What about 24-hour administrative support services available provided by the recruitment firm?

## TAKE HOME POINTS

- Locum tenens work can be an interesting and valuable way to gain diverse experience, work in different practice settings and locations, and augment income.
- Remember, however, that having multiple locum tenens positions on your resume may have the unintended effect of souring full-time employers on your application at a later time in your career. Too many locum tenens jobs is sometimes taken as a sign that the anesthesiologist could not get (or keep) a more permanent position.
- Locum tenens work may have much less "security" than an anesthesiologist is used to —perhaps only liability coverage (maybe). You should not consider it as anything

but a short-term financial arrangement.

- You and you alone will be looking out for your interests. It is imperative that you consult or hire the necessary tax and legal help to you do this.
- Remember, the recruiters are not ultimately looking out for your interests—they are looking out for their own interests in receiving a fee for your placement and being retained to do the next locum tenens placements.
- Maintain control!

## Suggested Readings


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# Your Career—Understanding Solo Practice and the Basics of Medical Practice Finance and Legal Organization

Norman A. Cohen, MD

In addition to the issues discussed in previous chapters, the assessment of solo practice opportunities has some unique considerations.

## Case Distribution

Unless you will be the sole practitioner for the facility, an admittedly rare circumstance, you will need to have an understanding of the **case distribution model** at your prospective facility. **Make sure that the case assignment system has reasonable checks and balances to avoid abuse.** This warning is particularly important when a large group has a significant presence.

The best case is having an independent party responsible for assignments. Also, if patient or surgeon requests are frequently made and honored, determine if there is any method to offset your lost income when one of "your" cases is taken from you. Without protection of some sort, lobbying of surgeons, direct advertising to patients, and other tactics have been known to result in an attempt to disproportionately direct patients to one of the competing anesthesiologists or anesthesia groups. This is a recipe for conflict, outlandish behavior, and dysfunctional anesthesia department function. I can hear the sound of consultants pounding on the door!

## Call Distribution

As with case distribution, assuring fair distribution of call responsibilities is exceptionally important in a solo practice. Sometimes additional calls can be financially beneficial, particularly when starting out in practice and trying to create good relationships with surgeons. In other situations, additional calls may be a problem. In either case, make sure that the opportunities for gaming the system are at a minimum.

In addition to handling after-hours cases, those on call often must manage acute pain

management issues such as epidurals and continuous nerve blocks, postanesthesia complications including postdural puncture headaches and persistent nausea or pain, and perhaps even calls from chronic pain patients for prescription refills, implantable pump issues, or other problems. Although many of these issues are common to all practices, as a solo practitioner you may find yourself saving patients from the misadventures of others or being forced to manage a treatment regimen far different from what you might have prescribed. At least in a group practice, you can weed out problem physicians and reduce your potential liability. You can also establish common protocols for managing specific issues.

## Anesthesiologist Relationships

In a setting in which the anesthesiologists are in multiple practices and are competing with each other for business, relationships can easily become strained. Assess the history of these interactions carefully. **Big warning signs include history of litigation between providers, hospitals threatening to enter into an exclusive contractual relationship, or a parade of consultants having visited the site in the recent past.**

Meet with your competitors before applying for privileges to practice. There may be a significant shortage of providers and you will be welcomed with open arms; however, much of the time you will be seen as someone trying to steal food out of the mouths of the other physicians' children. If your competitors are hostile and you still want to practice, at least you will know the challenges you will be facing.

## Control Versus Responsibility

As a solo practitioner you will have maximum control over your business. However, with that control comes responsibility—responsibility to your patients, to any employees or vendors, to your surgeons, and to your facility. You will bear complete responsibility for all aspects of managing your business. As a busy practitioner, you may not have adequate time to fulfill all your obligations. In that case, you will need to vet any businesses to which you may want to outsource some of your business functions. Most anesthesiologists do not have any significant experience or training in running a business; however, in solo practice, you **are** a small businessman or woman. If you don't take this seriously, it may cost you far more than you can imagine. It is no wonder that so many physicians are the victims of scams, bad investments, or outright theft from those to whom they delegated financial control.

## Finances/Accounting/Legal

Your net income will depend on having an effective billing and collection system. You

can do billing yourself, hire a person to do it for you, or outsource. **Given the complexities of billing and the significant financial risk if it is done incorrectly, I suggest outsourcing to a reputable firm.** Even large practices outsource billing and collections; however, unlike the large practice, you will likely not get the volume discounts that they enjoy.

Consider hiring an accountant and a lawyer to assist you in establishing your business correctly, paying all the necessary fees, and obtaining all required licenses. You can choose to track your finances and pay all your bills yourself, using the accountant only for tax preparation and the occasional consult for a specific issue. To see if this makes sense to you, weigh the accounting fees for routine bookkeeping to your opportunity cost—reduced time available to practice and generate income as well as reduced time with your loved ones.

Check with your state's medical or anesthesiology associations. They may be able to refer you to attorneys and accountants with particular experience in health care. Just as you would likely not see a family practitioner to manage your brain tumor (even though this has occurred on numerous television series over the years), you probably would not have a patent attorney review your insurance agreements.

Once your business is established, you will probably want to have your lawyer review contracts for you. Insurance agreements, accountable care organization affiliations, and independent practice association contracts are three common reasons to consult a lawyer. I am not a lawyer, don't play one on TV, but I have read more than my share of contracts over the years. The language is often arcane, and definitions of terms may differ substantially from what one might expect. There is an old saying in the legal profession that a lawyer who uses himself as his attorney has a fool for a client. If this is true for a lawyer, it is doubly true for a physician. Legal advice may be expensive, but not understanding your obligations under a contract may cost you far more.

## Legal Structure

When you establish your solo practice, you will need to set up the legal structure for your business. Your options depend on the laws in the state in which you will practice and include sole proprietorship, limited-liability company, partnership, and corporation. Corporations come in two varieties—Subchapter S and Subchapter C, referring to the section or "chapter" of the tax code in which they are defined.

When joining an existing group, decisions about legal structure will have already been made; however, you should still review the structure and understand the implications of the choices made before your arrival. In some cases, bad decisions on the part of the prospective practice may lead you to look for other opportunities.

The goals in choosing a legal structure are to minimize taxes, minimize

administrative complexity, and maximize liability protection. I will provide a very brief overview, but I suggest that you research this issue further. As a starting point, you can find useful information at the following websites:

) http://www.nolo.com/legal-encyclopedia/form-llc-how-to-organize-llc-30287.html
) http://www.sba.gov/category/navigation-structure/starting-managing-business/starting-business/choose-your-business-stru
) http://guides.wsj.com/small-business/starting-a-business/how-to-start-an-llc/

**Sole Proprietorship.** Sole proprietorships are the easiest to set up, requiring essentially no paperwork, but they provide no liability protection for your personal assets. Practice debts become your debts. Because of this lack of liability protection, this is rarely a choice that an anesthesiologist should make.

**Limited-Liability Company (LLC).** LLCs provide liability protection from the company's debts, contractual obligations, and legal entanglements for the owners (referred to as "members") of the LLC. A few exceptions do apply to these liability protections, though. LLCs are relatively simple to set up and have minimal reporting and administrative requirements. Also, income to the company passes through to the members, and the LLC is typically not subject to income tax. Most, but not all, states allow a single-member LLC. Also, in the past, at least, some states did not allow physicians to practice under an LLC. Where they are allowed, LLCs probably offer maximal protection with minimal administrative complexity of all the legal entities currently available.

**Partnership.** Although partnerships provide income pass-through, favorable tax treatment, and administrative simplicity, liability is joint and several. That means that if you subsequently bring in a new partner, you will be liable for any malfeasance performed or debt incurred by that partner. As with a sole proprietorship, partnerships are not a favored vehicle for physician practices because of the shared medical liability risk.

**Corporation.** A corporation provides liability protection for its owners/shareholders, but it has fairly strict administrative requirements, such as annual shareholder meetings, recording of minutes, and annual reports to the state. If these requirements are not met, the corporation could be considered invalid, the liability protections disappear, and the tax consequences could be extreme.

Subchapter C corporations, which are the standard, run-of-the-mill corporation (think Microsoft, Merck, or United Healthcare), may result in double taxation of profits. This means that corporate profits are taxed at the corporate tax rate and dividends to the shareholders are also taxed at the shareholders' tax rate. Careful accounting and distribution of income in the form of salaries to the employed shareholders can essentially eliminate double taxation for physician corporations, though.

Subchapter S corporations, which have limitations in number of shareholders (maximum of 75) and types of shareholders (no corporations, partnerships, resident aliens, and several other restrictions) do have the advantage of income pass-through to the shareholders, like LLCs and partnerships, without the risk of double taxation. However, in addition to the general risk of noncompliance with corporate requirements, failure to comply with specific Subchapter S reporting rules will risk losing the "S" status, with the potential for significant tax exposure and loss of liability protections.

## TAKE HOME POINTS

- Solo practice offers great flexibility and autonomy, but there are significant concerns, issues, and even risks.
- Thoroughly explore and understand case distribution and call distribution. Then go over it again before signing on the dotted line.
- Meet your colleagues and/or competitors before applying for privileges and don't be shy about looking for red flags—litigation between individuals or individuals and the institution and/or excessive use of consultants are two big ones.
- Be honest with yourself about your own aptitude and interest in running the legal and business sides of the practice. It's entirely reasonable and common to hire these jobs out to professionals—in fact, we recommend it. Look for experienced and reputable firms. You may need both legal help and a separate person or team for accounting help. Make sure you have an acceptable understanding of what actions are being taken on your behalf. Remember that the business of solo practice is ultimately based on your name, judgment, reputation, and responsibility.

## Suggested Reading

*Here is a site that describes physician corporation requirements by state: http://www.northwestregisteredagent.com/professional-entity-requirements-by-state.html (last accessed February 13, 2017)

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# Your Career: Make Sure You Understand the Compliance Plan

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Being "compliant" with procedural coding conventions and payer policies and requirements means that the professional group makes every effort to bill correctly. A compliance plan is the practice's organized effort to assure correct coding, identify and correct errors, and address ambiguities in a consistent manner.

Why is billing compliance important? **If government auditors determine that a physician has systematically but innocently billed incorrectly, any overcharges must be paid back, interest may be applied, and the physician may be fined $5,500 to $11,000 for each incorrect claim, with the possibility of treble damages.** If the physician "knowingly and willingly" submits fraudulent claims, the crime is a felony, with the potential for a $50,000 fine, imprisonment, or both. Decertification from Medicare is likely, making it exceptionally difficult for an anesthesiologist to be gainfully employed at any facility that accepts Medicare patients. Ignorance is no excuse when it comes to billing the federal government. For an overview of the various statutes that address fraud, abuse, and self-referral, check out http://www.cms.gov/Outreach-and-Education/Medicare-Learning-Network-MLN/MLNProducts/downloads/Fraud_and_Abuse.Pdf

**Although a compliance plan does not protect a group or physician from having to repay overcharges or eliminate the chance for fines, a group that demonstrates commitment to being compliant through implementing and following a plan will be much more likely to reach a reasonable settlement with the government.** I know of a number of groups, including my own, that identified problems through claims review, proactively addressed the problems with the government, and reached a fair settlement.

The Office of the Inspector General (OIG) has published a model compliance plan that includes these seven elements:

) Auditing and monitoring
) Implementing written standards and procedures
) Designating a compliance officer/contact

) Conducting training and education
) Responding to detected violations
) Developing open lines of communication
) Enforcing disciplinary standards

For those who like to go to the primary source, this link will take you to a reprint of the Federal Register issue where the OIG published the model plan: http://oig.hhs.gov/authorities/docs/physician.pdf.

The ASA Newsletter also includes a monthly column on practice management. Many columns have addressed compliance issues and creation of a compliance plan. For those with an interest, I suggest reviewing the many articles archived at the ASA site at http://www.asahq.org.

For purposes of evaluating a practice, asking the following questions may prove helpful in determining the group's commitment to compliance.

) Do you have a compliance officer?
) Do you have a handbook of coding policies available for your physician employees?
) Is there an ongoing process for reviewing codes submitted to assure accuracy?

The answers to all these questions should be a resounding "yes!" Although one can think of dozens of questions to ask about compliance, hearing any "no" answers to these very basic questions should be exceptionally worrisome. If you are an employee of a group that performs billing on your behalf, you are ultimately responsible that the billing is correct. Given your risk of monetary loss or even jail time, it is absolutely essential that you make sure your prospective employer takes compliance seriously.

## Billing and Collection Services

Some groups perform billing in-house, but many groups outsource billing to a third party. In either circumstance, an understanding of how to measure the performance of a billing service and the division of responsibility between physician and billing department is an important factor in practice analysis.

**Key Questions.** In evaluating a practice, at a minimum you should determine the following.

) Is the physician responsible for selecting the appropriate procedure code? Ideally, the physician should select the procedure code, because the code determines payment and incorrect procedural coding exposes the physician to compliance risk as discussed above.

) What about diagnosis codes? Many practices do not require the physicians to select diagnosis codes but do require thorough description of relevant diagnoses to support

the anesthesia, monitoring, evaluation and management, and pain management codes submitted. If you are required to submit diagnosis codes, the current edition of the International Classification of Diseases (ICD) should be readily available to you.

) If the physicians do code their procedures, what resources do the practice or billing service provide to assist the physician in selecting the correct code? At a minimum, the current year's ASA Relative Value Guide should be available to each physician. If the group requires submission of surgical codes on billing forms, the current year's AMA Current Procedural Terminology (CPT®) and ASA CROSSWALK® publications should be available as well.

) What process is followed if the billing clerk disagrees with the physician's choice of code or the supporting documents (anesthesia records, progress notes, dictations) are inadequate to support the choice? The charge slip should be sent back to the physician with the reason for the discrepancy, a suggestion about alternative coding choices, and a request for additional supporting documentation when indicated.

) Are the billing coders certified by a coding certification body? At least some of the billing staff should be professional coders. A number of organizations offer certification, such as the American Academy of Professional Coders and the American Health Information Management Association.

See Avoiding Common Anesthesia Errors, 1st Edition, Chapters 204 to 214 for more information.

**Assessment of Billing Service Effectiveness.** Often, the only question that a naive applicant asks a prospective practice about billing is the cost charged to perform this task. Although this is important to know, it is also crucial to remember that a billing service that is more effective in collecting revenue may be worth a slightly higher rate. Typical rates for outsourced billing range from 4% to 7% of the amount collected. Although I have never worked in a practice with in-house billing, my understanding is that the cost to the group is usually about 2.5% to 3.5% of net collections. Being a larger group, having more favorable demographics, or not requiring supplemental services from the billing company all help the group negotiate a rate toward the lower end of the spectrum when dealing with an outsource organization.

A number of measures are available to assess the performance of a billing service. Some of the most important measures include the following.

**Gross collection rate**—dollars collected divided by amount charged at the group's standard rate. For anesthesia-only practices, the average was just under 50% in 2004. This measure is useful primarily as an indicator that further analysis may be necessary. In statistical terms, it is sensitive but not specific. Drift in the gross collection rate may be due to many factors, including changing performance of the billing service, changes

in payer demographics, changes in payer contracts, changes in the overall economy, or a combination of these factors.

**Adjusted collection rate**—dollars collected divided by expected collections. Because practices often have contracts with insurers that promise a discount over the usual fee and Medicare and Medicaid payments are substantially lower than most practices' normal rates, this metric estimates the amount of dollars collectible for each charge based on insurer agreements and uses this estimate of net expected collections to calculate the collection rate. The average adjusted collection rate typically exceeds 90%. The primary sources of variation in this measure are inability to collect the patient's share of the fee and failure of the insurer to meet its payment obligations.

**Days fee-for-service charges in accounts receivable**—accounts receivable is the amount of money charged but not yet collected. Conventional practice is to post the full fee amount to accounts receivable when the charge is entered. The accounts receivable total is reduced whenever patient or insurer payments are collected. It is also reduced by the amount of any negotiated discounts or "contractual adjustments." Although accounts receivable is considered a financial asset, this is an asset that is not equivalent to cash in the bank. Think of accounts receivable as a loan to the insurers and patients that is receiving no interest and that you cannot use for any other purpose. The group's goal should be to keep the size of accounts receivable as small as possible through efforts directed toward rapidly collecting money owed to the group.

If one divides the accounts receivable by the average dollars charged in a day, one has a measure known as "days fee-for-service charges in accounts receivable," more frequently known as "days in A/R." The smaller this number, the more efficient the billing operation is in collecting the group's money. The national average for anesthesia practices is about 47 days. Factors that can increase this number include delays in submitting charges for billing, delays in entering the charges, delays in filing claims with insurers or patients, delays in payment by insurers or patients, and denial of claims by insurers for not following billing requirements or meeting medical necessity requirements.

You should note that some insurers have a track record of blanket denial of claims when they are initially submitted, forcing the practice to resubmit and be delayed in payment. Surprisingly, some practices never resubmit a claim after the first rejection. Consider this a "win, win" for the insurer!

Several large insurers, including Aetna, United Healthcare, Wellpoint, and Health Net, settled class-action lawsuits in the mid-2000's related to a pattern of inappropriate delays and denials in payment of claims. As part of the settlement, these companies had to establish physician advisory committees that served to review revisions in payment policies and compliance with the terms of the settlement. This author served on the

physician advisory committee for Health Net. These problems with payers have continued. To learn more, visit the AMA Litigation Center at http://www.ama-assn.org/ama/pub/physician-resources/legal-topics/litigation-center/about-us.page?, where you can review recent legal cases concerning these practices.

## TAKE HOME POINTS

- Fraudulent billing to federal reimbursement programs such as Medicare, if it can be shown by the government to be intentional, is a devastating professional, financial, and legal event.
- Liability and penalties can accrue even if the incorrect billing was inadvertent. If your practice realizes that inappropriate billing and payment has taken place, take proactive steps to address the problem.
- It is absolutely essential that you be familiar with the compliance plan of your practice. You cannot pass responsibility to the billing services contractor. The physicians are considered to be the responsible parties. The physicians will incur the penalties.
- Always make a careful assessment of your billing services contractor. Expect to pay between 3% and 7% of net collections. Cheaper is not always better!

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# Your Career—Know the Risk-Management Strategies of the Practice

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Although the improvements in the safety of anesthesia over the last several decades are nothing short of remarkable, anesthesia remains a high-risk endeavor. From the relatively frequent occurrence of dental injury to the lower-frequency but far more costly outcomes of permanent nerve injury, cardiac injury, lung damage, or death, practices should devote resources to risk reduction. Aggressive attention to risk management can lead to substantial reduction in medical liability insurance rates. Mandatory continuing education requirements, internal review of adverse outcomes, and requiring informed consent for all procedures are some of the characteristics you may look for in a risk-management program.

## Adaptability to Change

The environment in which a practice operates is constantly changing. From recognizing and addressing new competitive threats to accommodating new payment initiatives such as accountable care organizations and bundled payments, anesthesia groups must be able to adapt to and profit from change. To determine how your potential group manages change, you can ask open-ended questions about challenges facing the group and planned responses. If the group's leaders deny that any challenges exist or blame any and all problems on outside entities without offering any proposed solutions, dig deeper, as both are warning signs of possible problems. Although the group doesn't have to have a plan for every problem, it should have a well-defined process that will prioritize threats and lead to the development of a response. The process should be fairly inclusive, with input from all members of the group affected.

## Liabilities

Although it is not typical, some anesthesia groups may have debts that could affect your potential income. Whether the group bought a share in an ambulatory surgical center or a medical office building, or borrowed money to pay for fines, overcharges, or back

taxes, it is important for you to ask about liabilities before signing an agreement with the group. This is particularly important if you have an interest in buying a share of the group down the road, but it is also important because paying for or "servicing" these debts may affect the money available to pay employed physicians.

## Outstanding Litigation

Anesthesia practices may be involved in litigation for a number of reasons. Examples include being a named co-defendant in a medical liability case, being the subject of a billing investigation, being accused of antitrust violations or violations of workplace rules such as the Americans with Disability Act or the Family Leave Act, or suing a facility for improper termination of a contract.

You should try to understand the potential loss or gain and ongoing costs if your practice is involved in one or more lawsuits. Consider the litigation as future liabilities that need to be valued in evaluating your potential practice. The practice should be forthcoming in providing a reasonable amount of information when asked. Failure to disclose, unless under a court "gag" order, may suggest problems with trustworthiness and the group ultimately meeting its obligations to you.

### TAKE HOME POINTS

- The sources of risk and liability are many, ranging from dental injuries to transient and permanent nerve injuries to bad obstetrical outcomes to death.
- Every practice should have a way to assess and manage risk reduction on an ongoing basis.
- When you are evaluating a practice, ask open-ended and even leading questions. Listen carefully to the answers and be suspicious if problems are brushed aside or blame is shifted elsewhere. Take the answers back to the attorney who is helping you evaluate the opportunity and invest some time and money in talking over what you've been told. You should feel free to ask follow-up questions and if you don't, that could be a red flag.
- Ask specifically and directly about other financial liabilities such as fines, liens, and mortgages.
- Ask about and make sure you have sufficient detail about any recent, current, or likely litigation of any type. If necessary, have your own attorney evaluate the answers and review the possible ramifications for the practice **and you!**

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# Avoiding Bad Employment Contracts: Due Diligence, Termination, and Restrictive Covenants

Mark J. Baskerville, MD JD MBA MA

In this chapter and Chapter 303, I will provide you with an overview of important points to any employment contact: due diligence, term, and termination in this chapter; and duties, compensation, and benefits in Chapter 303. You should remember that this is an overview and my goal is not to cover all the possible clauses of an employment contract. The additional reading provides further references (at the end of Chapter 303). And it is always good legal advice to make sure you have an employment attorney look over your contract before you sign it.

## Due Diligence

Due diligence is not a step, but a process …

It begins by thoroughly vetting the prospective practice. Check their credentials as thoroughly as they are checking yours. Talk to everyone—including the nurses, surgeons, technicians, and administrative staff. If possible, get the contact information of practitioners who recently left the practice. Talking to them, as well as new hires may provide the most candid appraisal. It is essential to come away with a feeling of a mutually good fit and compatibility with the overall culture and vibe of the group.

Employment contracts are bilateral agreements that should always be negotiable. Since negotiations are a give-and-take venture, approach the conversation with a prioritized list of what is most important to you (e.g., schedule, salary, security, autonomy). Negotiate from a favorable position by emphasizing your talents. Highlight any specialty training or skills that can be exploited for the greater good of the practice. In essence, explain how you can bring value to their organization.

Once a mutual consensus is reached, **get it in writing.** Everything promised orally needs to be memorialized in written form. Since most contracts are composed by the employer's attorney, it is important to seek your own professional advice to protect

your best interests. Do not simply accede to terms you don't agree with, even if reassured that it is simply a standard contract that everybody signs. In the end, courts will enforce a clear and unambiguous contract regardless of your understanding or intent.

Finally, **when in doubt, get help**. An employment lawyer is best positioned to interpret the contract under the prevailing law and to represent your best interests.

## Term

An employment contract must answer four material questions:

) Who is the contract between?
) What is the term (duration)?
) What are the mutual duties and obligations?
) When and how are you paid?

The most important aspect of an employment contract is the term. Most contracts will stipulate a definite duration (i.e., 1 year). If the contract is silent, the default term is "At Will"—meaning that either party can terminate the contract at any time, if no notice provision is included. Accordingly, it is best to negotiate a fixed term contract with a clause permitting discharge only for cause.

Frequently a contract will contain an automatic renewal provision ("Evergreen clause") that states that the contract will renew for a like period if neither party terminates the contract before expiration of the term. Generally, you need to give notice that you do not wish to renew by the specified deadline.

Finally, be realistic about a start date. It can take months to obtain a medical license, hospital credentialing, staff privileges, and insurance coverage.

## Termination

Termination of the contractual relationship can occur for several reasons and the contract should address each of these situations.

## Without Cause

Either party can terminate the contract after a defined notice period. Sixty to ninety days is most common. Watch out for any provision that requires more than a 120-day notice to end a relationship without cause.

The notice requirement becomes important when you want to leave the practice. Failure to provide proper notice may result in liability for the costs incurred to the practice—such as hiring temporary staff.

## With Cause

Termination can only occur for a specific reason. "Cause" should be expressly defined in objective measures (e.g., willful misconduct, suspension of license, loss of privileges, failure to achieve board certification). If it is defined more subjectively, such as "poor performance," then make sure the contract requires a written notice of the alleged shortcoming and an opportunity to cure it. Likewise, the physician should be able to terminate the contract "For Good Reason" without any notice, if the employer breaches a material aspect of the agreement (i.e., failure to pay).

## Disability

Disability is an inability to perform the essential aspects of the job after a certain qualifying period, typically 3 to 6 months. However, the American with Disabilities Act (ADA) and the Family Medical Leave Act (FMLA) may afford some protection.

## Death

Death of the employee renders the contract void.

## Restrictive Covenants

A restrictive covenant is a promise not to do something. To prevent unfair competition, courts will enforce narrowly tailored covenants drafted to protect a legitimate competitive interest. Physician employment agreements typically include two restrictive covenants: Noncompetition and nonsolicitation.

A covenant not to compete prevents a former employee from providing similar professional services in a particular geographical area for a finite amount of time. A nonsolicitation covenant prohibits a former employee from soliciting the employer's patients and/or staff for a similar duration.

To be enforceable, these covenants need to be reasonable in scope, duration, and distance. As a rule of thumb, the duration should not exceed the lessor of the term of the contract, or 2 years, and the distance should not exclude a geographical area larger than that from which the practice draws the majority of its patients. Finally, these covenants must not unduly burden the physician or harm the public. If you are the only other anesthesiologist in a 100-mile radius, excluding access to your services would be deemed a detriment to the public, regardless of any resulting anticompetitive effect.

## Examples: Bad Contract Language

**TERM**

The Employer will employ the Employee for a term commencing July 1, 2018, and

continuing until terminated as herein provided for the purpose of rendering on behalf of the Employer professional medical services to such members of the general public.

WHY BAD: Try to avoid an undefined term. Even a term of 1 year subject to renewal is better than no definite term.

## TERMINATION

The Employee's employment shall be terminated:

a. By the Employee, by giving at least 180 days written notice to the Employer.
b. By the Employer, if the Board of Directors, in its sole discretion, finds that the Employee has engaged in unprofessional behavior.

WHY BAD: First, a180-day notice is unreasonable. A 90-day notice is the most common. Second, the term "unprofessional behavior" is subject to a variety of interpretations. Does it mean not answering your pages in a timely manner or committing a felony? Also, most "for cause" termination provisions allow an opportunity for the employee to cure the behavior.

## NONCOMPETITION CLAUSE

Employee hereby covenants and agrees not to practice medicine in any capacity in the State of Oregon for 5 years after the date Employee's employment terminates.

WHY BAD: Forbidding the practice of any form of medicine for 5 years within an entire state would be deemed unreasonable, and thus unenforceable, by any court.

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### Take Home Points For Any Contract

- A contract is a legally enforceable promise between at least two parties. To be enforceable, an employment contract must contain four material terms: parties, term, duties, and compensation.
- Due diligence is a multistep process of vetting a prospective practice, negotiating your priorities and memorializing the agreement in an unambiguous, written contract. Make sure all oral promises get converted to written promises.
- Read and understand every term in the contract before signing. Getting into a contract is easy; getting out is the hard part. Give yourself ample time to go over the contract, do not let yourself be rushed by the employer.
- **When in doubt, get a lawyer.**

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# Avoiding Bad Employment Contracts: Duties, Compensation, and Benefits

Mark J. Baskerville, MD JD MBA MA

In this chapter, we review the basics of an employment contract pertaining to job duties, compensation, and benefits. In Chapter 302, we reviewed due diligence, termination, and restrictive covenants.

## Duties

The contract must clearly state the job description and the mutual duties and obligations. What do you owe the practice, and in return, what are their obligations to you?

For the employee, the contract should specify all clinical responsibilities (including call), administrative tasks, and teaching obligations. It is important to stipulate the call burden and clarify whether it is to be shared equally with other physicians on a mutually agreed rotation.

For the employer, the contract must clearly define the duties owed in return. Common employer obligations include administrative support, billing services, office space, and equipment.

Most employment contracts contain an exclusivity provision stating that 100% of your professional time must be devoted to the practice. So, if you wish to have an outside professional activity (e.g., moonlighting, legal work, consulting), then it is mandatory to get it expressly incorporated into the contract.

Whatever the scope of the contractual duties, it is essential to emphasize the physician's paramount responsibility and fiduciary duty to the patient. Physicians must be able to exercise their independent professional judgment in all patient care.

## Compensation

Total compensation is not simply the salary you are paid—that is your paycheck. Total compensation includes everything of value provided in exchange for services rendered —including salary, bonuses, incentive pay, fringe benefits, and equity ownership in the

practice.

Four common monetary compensation models exist:

- 100% Salary: A fixed remuneration independent of productivity
- Base Salary ± Productivity: A fixed remuneration supplemented by incentive pay
- Equal Share: Egalitarian model where all practitioners split the revenue equally
- Pure Productivity: Income is solely dependent on productivity—"eat what you kill"

Many practices incorporate a "formula" to calculate the compensation. Such formulas include collections and incentive pay minus overhead and administrative costs. To better understand the nuances, ask the practice administrator to run a sample calculation with some hypothetical numbers.

Since all compensation formulas are based upon individual collections for professional services, a 60-day to 90-day lag period typically exists before individual revenue accrues. Most practices will extend interest-free loans during the first few months to be repaid as collections mature.

Lastly, vacation and sick days are considered compensation in all models except for the pure productivity paradigm. Here, if you are not working, you are not earning.

## Benefits

Fringe benefits can include:

- Insurance (malpractice, health, disability, life)
- Retirement plan
- CME and licensure reimbursement
- Professional dues and subscriptions
- Relocation stipends
- Loan repayment
- Signing bonuses

Any benefit package should be explicitly referenced within the contract or incorporated as an attachment. The contract should state which benefits will be provided at the employer's cost and which will require a contribution from the employee.

The phrase "the devil is in the details" is apropos for contracts and calculating total compensation. In particular, when comparing medical liability insurance coverage, you need to understand that they are not all the same. Three major categories of liability insurance can be offered:

- Occurrence. Coverage that indemnifies the practitioner against actions occurring during the policy period, even if the claim is filed after the policy lapses.
- Claims-Made. Coverage that indemnifies the practitioner against liability arising out

of claims filed during active employment with the practice.

- Extended Reporting Endorsement–-"Tail." Additional coverage that must be purchased with a claims-made policy. It insures against claims made after leaving a practice ("tail") or before new employment ("prior acts" or "nose").

As you can see, each policy covers a different time period, and hence, each has different values to you as an employee.

## Examples: Bad Contract Language

**DUTIES**

The Board of Directors of the Employer shall have the authority to determine the specific duties to be performed by the Employee and the means and manner by which those duties shall be performed.

WHY BAD: Too vague. The "duties" should be similar to a job description detailing exactly what is expected from you, and more importantly, what is not.

**COMPENSATION**

The compensation to be paid the Employee for services rendered to the Employer during the term of the Employee's employment shall be set, from time to time, by the Employer in such amount as it shall determine.

WHY BAD: It is essential to specify what and how you'll be paid. Agreeing to such a clause would leave you with no recourse should the employer refuse to pay you.

**BENEFITS**

The Employer shall, at its own expense, provide the Employee with professional liability insurance. Employee agrees to indemnify the Employer for any and all claims brought against the Employer arising out of any action by the Employee.

WHY BAD: It should specify what type of malpractice coverage. Is it occurrence or claims-made? Who is responsible for any tail insurance? Do not agree to indemnify the Employer under any circumstance.

## TAKE HOME POINTS

- Make sure the contract puts in writing the work hours and duties expected for the compensation. Don't get blinded by a dollar amount and not realize that you have to work 30 hours in a day to get that compensation.

- Total compensation is not simply monetary payments, but includes benefits offered as well as paid time off (vacation and sick leave).
- Don't simply compare salaries, but actually give a value to benefits and paid time off, then compare compensation.
- Read and understand every term in the contract before signing. Getting into a contract is easy; getting out is the hard part.
- When in doubt, get a lawyer. And remember, you will always be in some sort of doubt because you are engaged in the practice of medicine not the practice of law. So what we are saying is…get a lawyer!

## Suggested Readings


AMA principles for physician employment. American Medical Association. 2012.

Jeddeloh N, Conley T. Annotated model physician-group practice employment agreement. American Medical Association. 2014.

Kreager ML. A guide to understanding and negotiating a physician employment contract from the employee physician's perspective. Kreager Law Firm. 2007.

Semo J. "Chapter VII.1 Reviewing and Negotiating Employment Agreements" in Starting out: A practice guide for Anesthesiology residents. American Society of Anesthesiologists: Park Ridge, IL. 2010. Available from https://www.asahq.org/For-Students/Practice-Management/Resident-Practice-Management-Education-Tools.aspx

Stulberg RB, Shulman AF. Protecting physicians through employment contracts: a guide to the basic terms and conditions. Labor and Employment Law Journal. New York State Bar Association. 2013;38(1).

304

# MACRA—Robbing Peter to Pay Val (ue)

Brian T. Gierl, MD and Philip Carullo, MD

The Medicare Access and Chip Reauthorization Act (MACRA), enacted by Congress in 2015, was established to link care quality to payments for services and began in 2017. MACRA was passed to replace the Sustainable Growth Rate plan that was set to cut Medicare Part B[1] reimbursement to physicians by 20% in 2015. At least on paper, the MACRA program is better than a 20% cut, as ignoring MACRA reporting requirements entirely only cuts reimbursement by 4% to 9%. The Centers for Medicare and Medicaid Services (CMS) will implement the Quality Payment Program (QPP) to link remuneration to quality by participation in either the Merit-Based Incentive Payment System (MIPS), or Alternative Payment Models (APM). The entire plan is evolving under guidance from CMS. The QPP is the next generation all-in-one combination of the previous programs—Physician Quality Reporting System (PQRS), the Meaningful Use of Electronic Health Records, and the Value Based quality and cost platform—that offered bonus payments to eligible providers (EPs) for meeting certain quality measures, and penalties for not meeting those measures or failing to report them. The QPP also includes future annual adjustments for inflation that are greater for APMs to shift providers into APMs by 2025. The APM is a complex bundled payment model—that is, a standard, single fee paid to a hospital for a procedure with the hospital paying the physicians with a portion of that fee. APMs are still being redesigned by CMS with some APMs providing limited payments for the treatment of complications.

The QPP also includes a 0.5% annual adjustment for inflation until 2020, when the inflation adjustment freezes until 2025. To shift providers into APMs after 2025, the inflation adjustment for MIPS will be 0.25% annually, while those participating in APMs will enjoy a 0.75% annual adjustment for their participation.

For reporting purposes, physicians are grouped into one of two categories: “patient-facing” and “non–patient-facing.” “Non–patient-facing” is a very odd-sounding way of saying hospital-based providers and it applies to most anesthesiologists, CRNAs, and Anesthesia Assistants, although the strict definition is based on providers that bill less than 100 CPT codes to CMS. Under the new system, a “patient-facing” physician must meet many primary care objectives, which is an unfortunate requirement that may be

required of chronic pain physicians. That entire issue is well-described by the American Society of Regional Anesthesia (ASRA) in reference 1 and at the time of writing this book, is in flux. The Society for Critical Care Medicine (SCCM) has written on the subject here "Medicare's Physician Payment System Changes: Impact on Critical Care."

MIPS will grade clinician performance in four areas with a maximum score of 100. Weighting of each score will change annually. Annual scores will be made public. Non–patient-facing providers are exempt from having to report advancing care information (ACI) and have lower reporting requirements for clinical practice improvement activities (CPIA). The performance areas and weight of each score in 2017 are shown in Table 304.1.

MIPS is a means to score EPs in all fields on specialty-specific quality, resource utilization, and meaningful use of electronic health records—the anesthesia MIPS are listed in Table 304.2. Meeting those measures results in a bonus payment or a reduction in future fees; based upon prior year scores, underperformance would result in a negative rate adjustment (NRA) for future billing. To encourage reporting, CMS accepted partial year reporting of MIPS data in 2017 and will not use those MIPS results to negatively adjust 2019 reimbursement; simply reporting data avoided a negative rate adjustment. The ASA has advocated that CMS continue that program so that any EPs that reported data in 2018 would not be subjected to an NRA for reimbursement in 2020. That NRA will be 4% in the first year but increases to 9% after 2021. The ASA continues to lobby CMS to provide appropriate benchmarks for anesthetic care and to lobby Medicare to provide reimbursement that is proportional to the value of anesthetic care, as Medicare currently reimburses only ~33% of what is paid by private insurance. The ASA's "MACRA Advocacy" web page provides updates on this topic. The motivated reader might wish to gain information directly from CMS at their Educational Resources website that is also referenced at the end of the chapter (Table 304.2).

**Table 304.1 ■ Performance Areas for 2019**

| Measure | Weight | Note |
|---|---|---|
| Quality | 50% | See Table 304.2 |
| Advancing Care Information (ACI) | 25% | EMR Measures, probably will not apply to Anesthesiology |
| Improvement Activities (CPIA) | 15% | |

| | | |
|---|---|---|
| Cost | 30% | 2019 |

CMS will assess the cost component by first defining "Episode Groups," anesthesia EPs are most concerned with procedural episodes that could include: preoperative services, surgical procedure, anesthesia, followup care, services related to complications, and readmissions. The payment for such an episode would be adjusted for patient age, comorbidities, and illness acuity/severity to avoid financial penalties for treating complex patients. Cost may also be adjusted based on quality, based on complications and readmissions, procedure usage (overuse, underuse and misuse), patient functional status, and possibly patient satisfaction. Currently, the most commonly used assessment of patient satisfaction is the Press-Ganey Score and it does not directly assess satisfaction with anesthetic care. Initial guidance is expected in December of 2017 and it will undoubtedly evolve moving forward. Follow along at the CMS Website "CMS Quality Payment Program, Educational Resources," on the worldwide web referenced below (Table 304.3).

**Table 304.2 ■ MIPS Quality Reporting Measures for Anesthesia Providers in 2019**

| MIPS Number | Measure | High Priority |
|---|---|---|
| 44 | CABG: preoperative beta-blocker in patients with isolated CABG surgery. | **No** |
| 76 | Prevention of CVC-related bloodstream infections. Percentage of central venous catheter (CVC) insertions with all elements of maximal sterile barrier technique, hand hygiene, skin preparation and, if ultrasound is used, sterile ultrasound techniques followed. | **Yes** |
| 130 | Documentation of current medications in the medical record process | **No** |
| 404 | Anesthesiology smoking abstinence—Abstinence on the day of surgery | **Yes** |
| 424 | Perioperative temperature management—PACU Temp >35.5°C | **Yes** |

| | | |
|---|---|---|
| 426 | Postanesthetic transfer of care measure: Procedure room to PACU.[a]<br>Checklist or Protocol—The key handoff elements that must be included in the transition of care include:<br>1) Identification of patient<br>2) Identification of responsible practitioner (PACU nurse or advanced practitioner)<br>3) Discussion of pertinent medical history<br>4) Discussion of the surgical/procedure course (procedure, reason for surgery, procedure performed)<br>5) Intraoperative anesthetic management and issues/concerns.<br>6) Expectations/Plans for the early post-procedure period.<br>7) Opportunity for questions and acknowledgement of understanding of report from the receiving PACU team | **Yes** |
| 427 | Postanesthetic transfer of care measure: procedure room to ICU. See above. | **Yes** |
| 430 | Prevention of PONV—Combination therapy in individuals at high risk for PONV. Patients undergoing a general inhalation anesthetic who **have three or more risk factors for PONV** should receive combination therapy consisting of at least **two prophylactic pharmacologic antiemetic agents of different classes** preoperatively or intraoperatively. | **Yes** |

[a]Note that each element of the Transfer of Care need not be documented; you may simply document the use of an established checklist or protocol that encompasses the seven items.

**Table 304.3 ■ QPP Data From 2017 to Impact Reimbursement in 2019**

| Participation | Description | Payment Down-Adjustment in 2019 | Eligible Incentive |
|---|---|---|---|

| | | | |
|---|---|---|---|
| None | Report nothing, accept payment drop | Lose 4% | N/A |
| Minimal | Report on one quality measure or one improvement activity for 90 days in 2017 | No negative rate adjustment | 4% incentive |
| Moderate | Report multiple measures or improvement activities for 90 days in 2017 | No negative rate adjustment | 4% × incentive multiplier |
| Full | Report on all measures or improvement activities for all of 2017 | No negative rate adjustment | 4% × incentive multiplier + potential 10% bonus |

For participation in 2019, EPs are defined as anesthesiologists, CRNAs, and AAs who bill on more than 100 Medicare patients or charge Medicare Part B more than $30,000 annually as these requirements may be a burden to small practices. Kindly, MIPS participation will be phased-in with various options for participating EPs with details and adjustments being made in subsequent years.

The Incentive Multiplier is set so that the total annual penalties equal the incentives paid and is expected to equal 3.0. This ensures that the QPP does not reduce sum payments to EPs, the money is just redistributed as a reward to those EPs that meet their measures. CMS will additionally spend up to $500M as a value-based sliding scale bonus based upon the annual ranking of complete MIPS score reporting. In total, a full participant in 2017 could receive incentive payments of 22% in 2019: 3.0 × 4.0% + 10% Bonus = 22% Incentive. When the penalty and payment maximums increase to 9% in 2023, there is the potential for a 9% penalty or a 37% bonus.

Large institutions with extensive Quality Improvement systems may qualify as APMs and could receive a 5% payment incentive in 2019, if they receive more than 25% of their revenue in bundled payment plans. The APM participation requirement increases such that the billing entity should participate in enough bundled payment options that

they receive 50% of their Medicare payments from APMs for 2021 to 2022 and 75% thereafter. APM participation also includes the possibility of a 10% bonus for reporting certain high-priority items as well as a separate 10% bonus for submitting electronically—down with snail mail! Organizations that do not meet the APM participation level necessary for the 5% bonus may meet a minimum that will exempt them from penalties without reporting to MIPS. Those organizations may earn MIPS bonuses if they chose to report MIPS data.

To meet the CMS requirement, providers can submit MACRA quality data to them through one of two registry options, a Qualified Registry (QR), or a Qualified Clinical Data Registry (QCDR). Several CMS-approved QRs and QCDRs are available and are briefly described on the CMS website. The American Society of Anesthesiology's (ASA) Anesthesia Quality Institute (AQI) is one of several systems that are available to gather and report such data. The AQI reports from the National Anesthesia Clinical Outcomes Registry (NACOR), which tracks both MIPS and non-MIPS quality measures that can be reported to QR, QCDR, or both registries. QR reporting only accepts MIPS-based quality metrics (see NACOR Quality Reporting Options below) whereas QCDR accepts MIPS and non-MIPS metrics. A main benefit of reporting to both registries is that submission of all quality metrics, both MIPS and non-MIPS data, can be reported on all patients, regardless of their payer. This may become more important if private insurance companies develop their own quality based repayment metrics in the near future.

NACOR participation is free for ASA members and nonmembership pricing is available. Reporting to QR and QCDR can be submitted for an individual eligible provider (EP) or as an aggregate for a group practice. One advantage of group reporting is that if 75% of the group is non–patient-facing, then the group as a whole is considered non–patient-facing. This may be of particular concern for chronic pain specialists who would otherwise have additional reporting obligations as patient-facing providers. For most practices, metrics on at least 90% of patients will need to be submitted to CMS regardless of whether they are Medicare or non-Medicare patients. It is unclear at this time how CMS will utilize nonmedicare patient data. Several group practices have setup their own registries, including Drexel Health.

For those EPs or practices that worry about having the necessary IT infrastructure and software to properly submit patient data to NACOR, paid services exist that can help with development of quality measure selection, extraction and merging of data and reporting to NACOR.

In summary, if your practice isn't meeting the quality measures listed in Table 304.2, you should plan to implement those practices and find a means to report them. There are virtual groups that independent practitioners may join. The list of CMS-Approved

QCDRs an QRs that will help you to gather and report on quality measures is found here: https://www.cms.gov/medicare/medicare-fee-for-service-payment/sharedsavingsprogram/quality-measures-standards.html.

## TAKE HOME POINTS

- MACRA enables CMS to implement the QPP and to link reimbursement for services to quality as assessed by MIPS.
- The QPP will evolve over time with changes to MIPS and a push toward bundled payments (APMs).
- Quality metrics will be reported through QCDRs and QRs registries, data submitted to CMS and will include Medicare and non-Medicare patients.

## Suggested Readings


American Society of Regional Anesthesia and Pain Medicine. "MIPS Fact Sheet: Chronic Pain." MIPS Fact Sheet: Chronic Pain – American Society of Regional Anesthesia and Pain Medicine, www.asra.com/content/documents/chronic_pain_mips.pdf.

Aqi. AQI – Anesthesia Quality Institute, www.aqihq.org.

ASA MACRA Advocacy. American Society of Anesthesiologists, www.asahq.org/quality-and-practice-management/macra/ASA-MACRA-Advocacy.

MACRA and the Significance of Being "Non-Patient-Facing. Anesthesiology News, http://www.anesthesiologynews.com/Policy-and-Management/Article/06-17/MACRA-and-the-Significance-of-Being-Non-Patient-Facing-/41489.

MACRA Final Rule Released: 12 Things Anesthesia Providers Must Know for 2017. Anesthesiology News. McMahon Publishing, www.anesthesiologynews.com/Policy-Management/Article/12-16/MACRA-Final-Rule-Released-12-Things-Anesthesia-Providers-Must-Know-for-2017/38694/ses=ogst?enl=true.

Medicare's Physician Payment System Changes: Impact on Critical Care. SCCM.org, www.sccm.org/Communications/Critical-Connections/Archives/Pages/Medicare%E2%80%99s-Physician-Payment-System-Changes-Impact-on-Critical-Care.aspx.

NACOR Quality Reporting Options and Mechanisms. American Society of Anesthesiologists, www.asahq.org/quality-and-practice-management/quality-reporting-nacor.

Resource Library. Resource Library | Quality Payment Program, qpp.cms.gov/resources/education.


[1]Note that reimbursement under Medicare Parts A, C, and D are not impacted by this law, but Part B is the main payer for physicians and surgeons and accounts for ~15% of Medicare payments.

## SECTION XVI

# CONCLUSION

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# Sage Advice to Close This Book: Anesthesiology and the Aphorisms of B. Franklin, Printer

David A. Zvara, MD

Benjamin Franklin rose to acclaim through his writings and the expressions of his quick and insightful mind. During his lifetime he acquired a distinguished reputation as a Founding Father of the newly minted United States of America, a diplomat, publisher, inventor, librarian, Post Master, and more. Notably, despite his fame, he preferred to sign his public letters simply, and elegantly, B. Franklin, Printer. His aphorisms such as, "Early to bed and early to rise make a man healthy, wealthy and wise" and, "A penny saved is a penny earned" are known worldwide. The wisdom, generalizability, and succinct poignancy appeal to each of us. **Even Anesthesiologists.**

**"By failing to prepare, you are preparing to fail."**

–B. Franklin, Printer

Anesthesiology is characterized by the extremes of certainty and the unknown. We plan meticulously for the next exigency, the next step in the operation. We come prepared with plan A, B, C, and D (if not E, F, and G!). And yet, we do not really know from 1 minute to next what our fate shall be. Arriving at work ready for the three scheduled cases, one learns that a victim of an MVA with a ruptured spleen, multiple fractures, and loss of consciousness at the scene will bump their cases, with an arrival in the OR in 10 minutes, no less. We respond, because we are prepared. And yet, when, exactly, did this preparation begin? Was it that morning with a nutritious breakfast? That prior evening with a prudent decision to retire early ensuring a full night's sleep (and perhaps health and wealth, to boot!), or was it much longer ago? Did the preparation for this case start in residency with the hours of clinical work moving us from a clumsy novice to expert clinician? Was it medical school in which the foundations were first laid? Before this, even?

Where does preparation begin for an Anesthesiologist? We, who must respond at a

moment's notice, ready and able to save a life? Hard to say, yet, each step and each moment along the way matters. At the most base level, we understand that having our medications and equipment ready is necessary preparation. Staying current in the literature and leading quality improvement agendas are forms of preparation. Maintaining the physical and mental health necessary to bring our full attention to any crisis is preparation, too, without doubt.

For an anesthesiologist, there is neither beginning nor end to the preparation. There is only the simple truth that our patients depend on us, commit to us in a sacred bond of trust in which only we are the guarantors of true readiness. Surely, in our profession, when we fail to prepare, we are preparing to fail.

**"Beware of little expenses. A small leak will sink a great ship."**

–B. Franklin, Printer

Patient safety and quality improvement are a way a life for an anesthesiologist. Our profession has always led the House of Medicine in patient safety. Our collective commitment to understanding systemic threats to safety in delivery mechanisms, applied technology, and pharmacology have allowed us to reduce the morbidities and mortality associated with anesthesia and surgery. Our craft is safer now than ever and yet this journey is not yet complete.

Franklin promoted the principles of frugality and economic modesty. His aphorism on watching little expenses admonishes us to beware of those small actions that can summate for larger impact. His metaphor of the small leak sinking the ship is intended to warn us all of the risk we take in spending foolishly on small items leaving the larger, more important economic imperatives in our life vulnerable. In terms of patient safety, these little expenses come in the form of shortcuts in patient care that threaten both patient safety and our quality of care. Pragmatism and economic constraints are a reality; none of us can have it all, all the time. Yet, all of us must be the guardians of a common standard below which we will not travel. Staying ever alert, ever watchful, and ever ready against the little expenses of compromise that nibble away at the edge of our commitment to safety is central to ensuring the safe passage of our patient through the perils of perioperative waters. Beware small compromises; like small expense, a small leak can, indeed, sink a great ship.

**"Eat to please thyself, but dress to please others."**

–B. Franklin, Printer

Professionalism matters. In this age in which information and communication are instantaneous, there is ample evidence to suggest that codes of conduct and mores of

behavior are changing within our society. And yet, at each turn, we are often reminded that our success is rooted not on what we achieve alone, but in how we achieve success together. In other words, our ability to relate to others, to communicate our message to others, to gain trust, and give direction are not divorced from how we present ourselves outwardly.

In our private moments, we each are free to choose our environment. What we do for entertainment, what we read for general knowledge or leisure, how we rest, and how we exercise our bodies, are, much like our food, up to our discretion and taste. In these private matters, please thyself. When we seek discourse with others in business, we engage in a social contract with another. In the case of the physician, this social contract is not limited to the sterile transaction of unidirectional information sharing. Certainly, the patient comes to us wanting the right prescription, the right advice, and the skilled hand of care. But there is more. The patient comes to us seeking reassurance, trust, and peace of mind. How do we best provide reassurance, establish trust, and ease anxiety? Do we simply say it, and it is so? No. These elements come from our outwardly presentation, our demeanor, and demonstrated empathy. Sit when talking to a patient and their family. Look at your patients directly and without judgment. Smile and listen, really listen when your patient speaks to you. These are the clothes we wear in patient encounters. Wear them well.

**"When you're finished changing, you're finished."**

–B. Franklin, Printer

Change in medicine is certain, in fact, it is the only thing we can count on. What we learn today and hold as true may very well fall in the years and decades ahead. We have seen this time and again as new research promises breakthroughs in cancer care, heart disease, and other maladies—only to be subsequently refuted over time. The mysteries of life are ever unfolding and one discovery most certainly leads to the next. One understanding serves only as a rung on the ladder, the destination still ahead.

The physician anesthesiologist must welcome continual change. Imagine a world in which innovation was stifled leaving us to administer anesthesia by open drop or copper kettle, a finger on the pulse, and an eye on the color of the blood? Change is uncomfortable, challenging, overwhelming at times, and always, necessary. As a professional, commitment to this change manifests through maintenance of certification and updating skills and knowledge. Change is committing to financially supporting the Foundation for Anesthesiology Education and Research or other research activities ensuring that our profession has the resources available to materially create the new knowledge.

Innovation in education allowing the transmission of this knowledge is the second

imperative of change. Without the effective transmission of information, growth is inhibited, if not extinguished. If we as a profession, or we as individuals, stop changing, w e are finished. Franklin once wrote, "Many people die at twenty-five and aren't buried until seventy-five."Let this not be us. Not our Profession. Embrace change. Lead change. Create new knowledge or, at the least, contribute materially to this creation. Embrace innovation. Teach others. Learn. Live.

Benjamin Franklin's words reach across the centuries ringing true even today. His common sense approach, and his simple message delivered through wit and metaphor capture our culture and our humanism. In Anesthesiology, we can immediately see the applicability of the following expressions to how we manage in the operating room, the intensive care unit, the pain clinic, and beyond:

"Diligence is the mother of good luck."
"It is easier to prevent bad habits than to break them."
"Distrust and caution are the parents of security."
"When in doubt, don't."
"Take time for all things: great haste makes great waste."

All of these sayings are as rich in meaning today as they were when first published in the mid-eighteenth century. The lessons initially intended for the city dweller and farmer in colonial America can be applied to each of us in our community practice or the hybrid operating room in the quaternary care hospital. Yet, among all of these wise and applicable saying, I wish to close with two final quotations:

**"Don't think to hunt two hares with one dog."**

–B. Franklin, Printer

Distractions abound in our world and as we move into a global information economy driven by instantaneous connectivity. The opportunity for each of us to lose focus and achieve little is, perhaps, greater than ever. If we allow ourselves to overreach, multitask, and assume that kinetic activity somehow translates into meaningful result, we shall be as foolish as the hunter who chases two hares with one dog, for surely, the result will be no hare at all.

And finally:

**"Wine is constant proof that God loves us and loves to see us happy."**

–B. Franklin, Printer

As a fellow deist with my long departed brother, B. Franklin, Printer, I need say no

more.

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