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Trauma Team Dynamics

A Trauma Crisis Resource Management Manual

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For our families, whose endless support makes this all possible.

Foreword

Trauma Team Dynamics is a very timely text delivered when there is currently a North American effort to improve patient safety and quality. This text is authored by an international, multidisciplinary group of authors who are recognized as leaders in their respective fields.

Trauma care is particularly challenging, as optimal patient outcome demands the efficient integration of multiple disciplines. Individuals with diverse training and experience are constantly striving to define a spectrum of unknown injuries. Their ultimate goal is to provide care prioritized according to their skills to address the most time-sensitive injuries.

Collaboration begins at the moment an injury is observed, when often a nonmedical person calls the Emergency Medical System (EMS) via 9-1-1, and must convey key information in a concise and organized fashion. We often forget the importance of this initial communication until we are reminded by the reviews of EMS tapes on news media. The need for clear communication and cooperation escalates at the injury scene where often police, fireman, ground paramedics, and flight nurses arrive at different times to determine their respective role in managing a critically injured patient. It is at this moment that the fundamental concepts of leadership, teamwork, communication, and situational awareness become operational.

The ensuing prehospital report, based on collective information, dictates the composition of the trauma team in the Emergency Department (ED) that is assembled prior to the patient's arrival. The need for leadership, teamwork, and communication intensifies as the complexity of the trauma team increases. There is a no more challenging environment than the blunt multisystem injured patient arriving to the ED comatose and in shock.

While the American College of Surgeons Committee on Trauma's Advanced Trauma Life Support (ATLS) Course provides guidelines for early care of the injured, the timing and implementation of interventions are often modified as the injury pattern is better defined and the patient's response to these resuscitative efforts is determined. The philosophy of damage control resuscitation is a cogent example. Coordinated teamwork among trauma surgeons, emergency physicians, ED nurses, neurosurgeons, orthopedic surgeons, physician assistants, nurse practitioners, ED technicians, as well as respiratory, laboratory, and radiology support is essential. Teamwork in the operating room (OR) has been a major patient safety issue over the past decade, and this text provides additional recommendations to ensure this important goal. The critical decision to shift from definitive operative care to damage control surgery requires clear communication among the OR team. The need for constructive team dynamics in the intensive care unit (ICU) is well known as the team confronts challenging issues daily from the necessity of diagnostic testing to end of life issues. Finally, this text reviews the essential requirement for leadership, teamwork, communication, and situational awareness in tactical emergencies and disasters.

Changes in the management of trauma as well as the evolution of technology have led to many lives being saved over the past few decades. However, the way in which we function as a team ultimately can influence whether or not a patient sustains further morbidity, and/or mortality. Developing these nontechnical skills is essential to promoting and sustaining quality care not only in tactical emergencies and disasters but also in every aspect of medical management. It is a focus on these *Trauma Team Dynamics* that will help shape trauma care over the next century.

Denver, CO, USA Ernest E. Moore, M.D.

Preface: Trauma as a Team Sport

The American College of Surgeons Advanced Trauma Life Support (ATLS®) Course has revolutionized trauma care by offering a standardized, reproducible and universal approach to trauma patient management. ATLS® however focuses on management by a solo practitioner which is rarely the case in modern trauma care. The introduction of a trauma team, no matter how small, brings with it new challenges and dynamics. To date no text (including the ATLS® manual) has addressed the unique dynamics created by a multidisciplinary trauma team and strategies to optimize them.

Further, morbidity and mortality reviews reveal that the majority of medical errors are nontechnical in nature, stemming from faulty decision-making, asynchronous information gathering, lack of situational awareness, and ineffective communication and team leadership. Reviews of accidents from other high-risk industries, including the airline industry, have had similar findings. This led NASA (National Aeronautics and Space Administration) and the airline industry to develop crew (now crisis) resource management (CRM) training. Medicine has begun adapting this training especially within the realms of anesthesia and critical care. Trauma surgery has been slower to utilize this work; however simulation-based training is increasing in popularity. These team-based training strategies address "nontechnical" skills to counteract human error and improve team and patient safety.

CRM is integral to the way that we manage ourselves, team members, and patients during emergency situations. It is essentially the ability to translate knowledge of what needs to be done into effective actions during a crisis situation. There are numerous publications on trauma diagnosis, management, and treatment of injuries, but little literature exists on communication within the trauma resuscitation, and how communication can be utilized to improve teamwork and crisis management, and potentially improve patient resuscitation outcomes.

This book is in no way meant to replace ATLS® training, but instead build on ATLS® principles and highlight how they can be applied by a multidisciplinary trauma team. This textbook represents a unique standalone reference for others trying to teach or learn these Trauma Team Dynamics. Authored by an international group with a broad expertise in trauma, critical care, emergency medicine, nursing, respiratory therapy, and prehospital care (including NASA and United States military affiliated experts), we feel it forms a comprehensive, multidisciplinary manual for all trauma team members including pre- and out-of-hospital personnel, emergency and critical care physicians, trauma surgeons, nurses, and respiratory therapists, as well as their respective trainees.

The textbook was initially developed to serve as an accompanying manual for a multidisciplinary trauma team training course called STARTT (Standardized Trauma and Resuscitation Team Training). This training course was developed by a team of trauma surgeons, intensivists, emergency physicians, nurses, and respiratory therapists who are Canadian leaders in the field of Trauma and surgical education.

Part I highlights the history of CRM including its beginnings with NASA and the airline industry, and its evolution to other high-risk industries including medicine. It goes on to introduce us to the guiding tenants of CRM and how they can be applied practically in a trauma setting. These concepts continue to be woven throughout the text as we highlight the importance of CRM principles while following the trauma patient from the scene, through prehospital care and transport, to the trauma bay and finally to definitive care.

In Part II we discover the structure of the modern trauma team, including prehospital personnel, highlighting the roles of the various trauma team members and design of the typical trauma bay. We also briefly explore the logistics of trauma system design and important quality control issues.

Part III begins with a review of ATLS® and resuscitation principles and then offers a practical and comprehensive approach to damage control resuscitation not seen in other texts. It goes on to discuss the complexities of trauma decision-making and ends with a practical highlight of common trauma bay procedures.

Part IV stresses certain challenges in the trauma management of specific patient populations including the pediatric and pregnant patient as well as the patient with multiple medical comorbidities and the elderly.

In Part V we discuss conventional and point of care imaging in the trauma patient including an in-depth look at basic and advanced trauma ultrasound, and new emerging techniques.

Part VI takes trauma to the battlefield, the mountaintop and beyond with discussions on tactical and battlefield medicine, trauma in austere environments, and even space. In the course of this discussion, we emphasize the unique challenges of chemical, biological, and nuclear injuries and how these affect both the patient and the trauma team.

Finally, crisis resource management skills are best taught through a crisis simulation curriculum and therefore Part VII offers practical tips and guidance on CRM curriculum design, debriefing, and evaluation.

It is our sincere hope that this text serves as a catalyst to improved communication in the trauma bay, improved multidisciplinary training of team members, and ultimately improved patient care. Trauma truly is a Team Sport and its time to finally teach it as such.

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Part I

Trauma Team Preparation

1 The Genesis of Crew Resource Management: The NASA Experience

David J. Alexander

Humble Beginnings

The National Aeronautics and Space Administration (NASA) has been intimately involved with the process of crew resource management (CRM) and one of the early innovators of the systematic procedures to eliminate human error in the cockpit. The first effort was the development of the aviation checklist. This was due to the crash of the Boeing Model 229 aircraft on October 30, 1935. The Boeing Model 229 was an extremely complex aircraft for the time. It had many revolutionary design elements incorporated. The pilot, who had never flown the Model 229, had neglected to release the elevator lock prior to takeoff. The Boeing chief test pilot aboard the aircraft, Leslie Tower, realized the error once airborne. He attempted to release the lock, but was too late to save the doomed aircraft. The design was in serious jeopardy after the crash. The press had labeled the aircraft as too complex to fly. Army Air Corps officers pleaded to proceed with the project, and eventually, 12 aircraft were delivered to the second Bombardment Wing at Langley Airfield in Virginia. It was emphasized to the pilots that any further accidents would result in the cancelation of further orders. The pilots came together and developed four checklists. These were the takeoff, flight, pre-landing, and after landing checklists. They eventually proved that the Model 229 was not "too much aircraft for a man to fly"; it had systems more complex than any one man's memory. These checklists were the assurance that no item was forgotten. These 12 aircraft went on to safely fly 1.8 million miles without a serious accident. The Model 229 went on to be developed as the B-17. It was one of the workhorse bombers of World War II and helped to destroy Nazi Germany's war industries. The checklist was then integrated into subsequent Air Corps aircraft and then the civilian airline industry.

Human error as a cause for an accident was placed in the public eye again on the night of December 29, 1972. An Eastern Airlines Lockheed L-1011 Flight 401, would be a sentinel event in safety. Flight 401 was en route from JFK Airport, New York, to Miami International Airport. The Lockheed L-1011 had rolled out of the factory only 4 months previously. This particular flight carried 163 passengers and 13 crewmembers. The journey was routine up until 11:32 p.m. The aircraft was on approach to Miami International and the landing gear was lowered. The landing gear indicator was not illuminated, indicating the gear was not down and locked. The landing gear was cycled again and the illuminator still did not light. The light on the indicator was burned out and the cockpit crew began replacing the bulb. The crew discontinued the approach and began a circling pattern to work on this problem. The second officer was sent into the lower avionics bay to view through a small window and confirm the gear was down. The aircraft autopilot was activated to maintain 2,000 ft. During this time, the pilot accidently leaned against the yoke (control column) and changed the modes on the autopilot from altitude hold to CWS (Control Wheel Steering—in which the pilot controlled the pitch of that aircraft). This forward pressure also started the aircraft to descend. After descending 250 ft, a C-cord alarm was sounded in the cockpit. This alarm was designed to alert the crew that they had descended from their assigned altitude. The frustrated, fatigued crew who were concentrating only on the burned out light did not notice the alarm.

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The engineer was not on the flight deck as well and could not have heard the alarm from the avionics bay. The plane was over the Everglades at night, and therefore, there was no ground references to indicate the plane had descended. In 50 seconds, the aircraft was now down to 1,000 ft. The co-pilot then initiated a 180° turn to maintain a holding pattern and noticed the discrepancy in altitude. This triggered the following conversation.

Co-Pilot: We did something to the altitude.
Pilot: What?
Co-Pilot: We're still at 2,000 feet, right?
Pilot: Hey—what's happening here?

Ten seconds later, the aircraft impacted the Everglades. This resulted in the deaths of 101 persons and was the first accident of a wide-bodied airliner. At that time, it was the second deadliest single aircraft disaster in the United States [1–4].

Another accident around this same time period highlighted human error in the cockpit. United Airlines Flight 173 (UAL 173) was making its final approach to Portland International Airport after a routine flight on December 28, 1978 [5]. The aircraft ran out of fuel and crashed into a residential area, killing eight passengers and two crew members and seriously injuring 23 others. While circling, the first officer and flight engineer told the pilot that the plane was running low on fuel. The pilot ignored the warnings of his junior officers. These and other accidents aroused the interest publically in accidents due to human error.

In all of the cases, the aircrafts were mechanically sound; the crews were experienced and technically competent. The system at the time simply did not catch mistakes in time to prevent these fatal errors. In 1978, the Military Inspector General determined that poor crew interactions were a major factor in aircraft accidents. NASA then led the way to change the aviation community to prevent these accidents from occurring. In 1979, NASA conducted the *Resource Management on the Flightdeck* workshop at the Ames Research Center [6, 7]. NASA had for many years been conducting research into human factors and performance in aviation since the early 1970s at the Ames Research Center. In 1973, interviews with aircrews were conducted, and this highlighted the lack of training for airline Captains in leadership. H.P. Ruffel-Smith (1979) conducted a 747 simulator-based study on human behavior [8]. He found that in both routine and emergency simulations, the better the cockpit resources were utilized and using effective crew communications, the better the performance in the cockpit. Several other studies suggested that incorporating "crew resource management" into routine flight operations training would greatly aid in preventing these accidents. During the workshop, it was soon discovered that 60–80 % of aviation accidents were the result of human error. Clearly, the aviation industry had to change. After another NASA/Federal Aviation Administration (FAA) workshop conducted in January 1981, the FAA began incorporating a CRM platform into its regulatory program. United Airlines was the first to add CRM into its training syllabus in 1981.

A New Paradigm Is Born

Crew resource management does not focus on technical aptitude or skills. CRM focuses on cognitive and interpersonal communication needed to organize a complex aviation environment. Cognitive skills focus on situational awareness, planning, and decision-making. Situational awareness provides an organized way to recognize salient factors and conditions that affect the safe operation of the aircraft. Planning takes the decision construction process across all phases of the flight. This also incorporates subordinate input into the decision formation process, but still maintains a hierarchical structure with the Captain retaining authority and responsibility of the flight. Interpersonal skills concentrate on communications and team building. Essential to CRM is communication. Research has proven that good communication not only transfers accurate information but helps to build a unified understanding of the problems at hand. It helps everyone to build a mental model of the environment and enhances situational awareness. Team building incorporates the entire crew's skills and experience resulting in the combined efforts far exceeding the capability of one individual. Emotional climate and stress management skills are also taught in CRM training. Research showed that the creation of a positive tone on the flight deck enhanced the cognitive and interpersonal proficiencies of the crew. Stress management in the cockpit can be managed by an organizational culture that efficiently assigns tasks and establishes priorities. This also incorporates the empowerment of subordinates by training them in the skills which will enable them to take on additional responsibility when the circumstances demand it.

The airlines embraced CRM training as well as the military. NASA took these concepts and incorporated them into the shuttle training program. One aspect of CRM was simulation training in the management of complex contingency operations that occur in spaceflight. These had been incorporated into the NASA culture since the earliest phases of spaceflight. From Mercury through today's International Space Station training, simulators have been a mainstay of spaceflight practice. NASA has also learned hard lessons from its failures. The Challenger accident highlighted several lapses in the NASA "Safety Culture" that contributed to the disaster. The investigation highlighted NASA's and Morton Thiokol's failure to respond to the design flaw of the

O-rings in the Solid Rocket boosters. Rather than redesign the joint, it was defined as an acceptable flight risk. This was the "Normalization of Deviancy" or the violation of standards of practice repeatedly such that they actually become routine over time. This occurs by errors, lapses, or mistakes that go unattended, unappreciated, or unresolved for an extended period of time. The report also impugned the decision to launch. It cited numerous failures in communication that resulted in a decision to launch 51-L. The decision was based on "incomplete and sometimes misleading information, a conflict between engineering data and management judgments, and a NASA management structure that permitted internal flight safety problems to bypass key Shuttle managers" [9].

Attention once again focused on the attitude of NASA management towards safety issues in 2003, after the Space Shuttle *Columbia* loss. The Columbia Accident Investigation Board (CAIB) deduced that NASA had not incorporated the lessons of *Challenger*. One highlight was that the agency had not set up a truly independent office for safety oversight. The CAIB concluded that in this area, "NASA's response to the Rogers Commission did not meet the Commission's intent" [10]. The CAIB believed that "the causes of the institutional failure responsible for *Challenger* have not been fixed" [10]. They declared that the same "flawed decision-making process" that had culminated in the *Challenger* accident was at fault for *Columbia*'s destruction. The *Challenger* and *Columbia* accidents are now used as case studies in how several concepts in CRM broke down. The lessons for NASA were breakdowns in communication and lapses in group decision-making and, most importantly, revealed the dangers of groupthink (in which the desire for conformity or amity in a group results in a deviant or flawed decision-making conclusion).

NASA continues to improve the CRM process. The shuttle crews incorporated CRM directly into their training. These Shuttle Transportation System (STS) crews underwent numerous case simulations of normal and emergent situations. These incorporated the lessons learned from aviation and the shuttle accidents. These were incorporated into CRM for the entire shuttle operational teams. The crews were together for several years prior to launching. This included not only the mission's onboard crewmembers but the Mission Control Teams dedicated to the particular missions. Numerous crew bonding activities to promote communication and team building were incorporated into training regimens. Events such as the National Outdoor Leadership School (NOLS) classes to teach leadership became important in astronaut training. These sessions incorporate leadership curriculum, outdoor ethics, and wilderness skills to help develop good leadership and communication. NASA management also undergoes CRM training to produce a true safety culture. These lessons are still integral to the International Space Station training and the future mission culture of NASA.

Medicine has also learned from these experiences in aviation. Helmreich and Schafer proposed using the NASA-inspired crew resource management from the airline industry in operating rooms [11]. Subsequent to that in 1999, Sexton et al. compared flight crew interactions with operating room staff. This extensive multiyear study showed a remarkable difference in the attitudes about teamwork. The surgical staff showed that the surgical attendings and residents reported high levels of teamwork, but the ancillary staff (anesthesiology attendings, residents, nurses, and OR nurses) reported exceptionally low levels of teamwork. A significant amount of attending surgeons preferred the use of steep hierarchies (with junior team members being limited in questioning the decisions and actions of a superior). This was in stark contrast to the airline crews, instilled with the crew resource management styles, who 94 % preferred the flat hierarchies (in which junior members are encouraged to voice concerns about the senior members choices and decisions) [12]. The study also revealed the attitudes toward fatigue. A vast majority of the surgical staff agreed with the statement "Even when fatigued, I perform effectively during critical times." In stark contrast, only 26 % of the fight crews agreed with that statement [12]. In 2000, a landmark report from the Institutes of Medicine (IOM) was released that sparked a large amount of public debate. The report *To Err is human: Building a Safer Health System* examined medical errors in healthcare systems. The report cited results from Colorado and Utah that up to 44,000 people died due to medical errors. It then went on to refer to one New York study which indicated that up to 98,000 died due to errors in the medical system [12]. The report then concluded emphatically "healthcare is a decade or more behind other high-risk industries in its attention to ensuring basic safety." These lead to public outcries which subsequently lead to President Bill Clinton executing an executive order to require federal departments to develop safer practices in healthcare [13]. This leads the Joint Commission on Accreditation for Healthcare Organizations (JCAHO) to support aviation teamwork applications in training programs for hospitals [14, 15].

The Sexton study and several other papers around that time triggered numerous changes to training programs which incorporated aviation-inspired crew resource management. Critical areas such as the emergency departments, operating suites, and labor/delivery were identified as those areas that could benefit from CRM training [16–18]. Anesthesiology incidents that were related to human error were proclaimed to be as high as 65–70 % [15]. This prompted the VA Palo Alto Health Care System and Stanford University to develop the Anesthesia Crisis Resource Management (ACRM) system based on CRM [16, 19]. The Army Research Laboratory and Dynamics Research Corporation developed the MedTeams behavior-based teamwork system. This drove military-based aviation experience into the Emergency Medicine training [18]. This system was expanded into Labor and Delivery units. The system eventually drove specific training and assessment tools incorporated into the Emergency Team Coordination Course. Similar to aviation CRM, the entire philosophy was centered on avoiding errors, ensnaring errors when they occurred, and mitigating all the consequences of decisions and actions that may have been taken in error. Peer monitoring is critical in all the medical CRM approaches. This insures maintaining adequate situational awareness during essential dynamic medical procedures. This then aids in incorporating good practices to procedure and improving training programs.

There is much debate currently on the effectiveness of CRM in medicine. Like aviation, it is difficult to show direct correlations to improvements in safety. Studies are challenging to design, and very few studies to date incorporate a control group. Subjective and anecdotal data do suggest that aviation-based CRM in medicine is an improvement in the culture and training previously offered [16, 17, 19, 20]. Aviation has the advantage of 20 years of CRM training and experience. The improvements in performance for pilots have been shown in yearly evaluations, actual flight performance evaluations, and simulator training. The NASA/University of Texas Line/LOS Checklist (LINE/LOS Checklist) rating scales for critical crew performance during different phases of flight has shown improvements [21–23]. Again NASA helped lead the way for safety improvement and evaluation. Analogous studies need to be performed in medicine.

Shifts in the culture of medicine to shift from centering only on technical expertise to include the facilitation of human interactions will take time. This effort is only now getting started. Crew resource management is a new paradigm in a centuries-old institution. This book marks a first step in introducing CRM to the trauma bay.

Key Points

- NASA has been intimately involved in aviation safety since the 1970s.
- Several airline accidents gained public attention when very experienced crews became distracted and initiated a series of errors that led to major accidents.
- Groundbreaking studies on human performance by NASA Ames Laboratories led to the NASA/FAA workshop in January 1981 to recommend crew resource management (CRM) to be incorporated into aviation safety.

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- CRM focuses on cognitive and interpersonal communication needed to organize a complex aviation environment.
- NASA incorporated CRM into its safety culture, followed closely by the US Military and the major airlines.
- Reducing human error in the skies and in hospitals is a noble endeavor.

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2 Crisis Resource Management Training in Trauma

Christopher M. Hicks

Introduction

Error is ubiquitous in trauma care, occurring in as many as 100 % of trauma resuscitations [1]. The trauma room represents a perfect storm for adverse outcomes; multiple team members of various backgrounds and training levels, holding different and often competing patient care priorities, must interact in the face of diagnostic uncertainty, high patient acuity, and extreme time pressures to rapidly diagnose and manage multiple potentially life-threatening injuries.

Prior work has established a taxonomy of common errors that occur during the care of the trauma patient, which are known to have a detrimental effect on patient outcomes [2, 3]. The majority of these errors are nontechnical in nature, stemming from faulty decision-making, asynchronous information gathering, lack of situational awareness, and ineffective communication and team leadership.

Accordingly, there is a need to develop team-based training strategies that address these nontechnical skills as a specific strategy to counteract medical error and improve patient safety. Simulation-based team training has its origins in high-risk industries such as civilian and military aviation and has been used effectively in health to train teams in surgery, critical care, and emergency medicine, improving patient safety and decreasing error rates [4–6]. Team training is not a "one-size" intervention, and training applications need to be adapted and developed to suit domain-specific needs [6–8].

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The Case for CRM: Origins of Team Training in Aviation

Aviation may be classified as a high-hazard industry: the safety of flight crew, and, in the case of commercial aviation, passengers depends on the precise execution of multiple high-risk maneuvers coordinated by a team of skilled pilots and technicians. Over the past several decades, the commercial aviation industry has garnered wide recognition for its safety record, taking its place among military and nuclear operations as an example of a high-reliability organization (HRO). HROs are organizations that exist in hazardous environments where errors carry high consequences, yet the error rate is extremely low [9].

Prior to the 1980, training of civilian and military pilots focused almost exclusively on the technical aspects of flight [10]. Prompted by a series of high-profile, high-fatality airline incidents, the aviation and aerospace industries began to take a critical look at why planes crashed. An example is the Tenerife disaster in 1977, where two fully loaded jumbo jets (KLM Flight 4805 and Pan Am Flight 1736) collided on the runway of a small Canary Island airport during a failed takeoff maneuver, killing 583 passengers and crew members—the most fatal disaster in aviation history. A large, international panel of experts was involved in the crash investigation, which implicated errors in communication, rushed and incomplete procedure, and failure to challenge the decision-making of senior KLM Captain van Zanten when it was obvious to crew members that his actions were hasty and ill-informed [11].

In 1976, the National Aviation and Space Agency (NASA) began collecting data on all aviation mishaps via the Aviation Safety and Reporting System (ASRS). Designed in close cooperation with the aviation industry, the ASRS was a voluntary reporting system created to assist in the analysis of aviation catastrophes and near misses [12]. Early reports from the ASRS implicated human error as the root cause of

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60–80 % of all aviation incidents [13]. The US General Accounting Office reported that a lack of team coordination, failure to assign tasks, and lack of effective leadership and supervision were a contributing cause in nearly half of fatal accidents between 1983 and 1985 [14]. In 1984, Billings and Reynard published a review of 7 years of data and over 35,000 reports in the ASRS in an attempt to better understand and classify the nature of consequential cockpit errors. The majority of events could be attributed to either human or system factors: at the system level, over 70 % of reported incidents involved faulty information transfer [12]. Although information quality was typically not the culprit, failure to effectively communicate key data to the personnel responsible for tactical decision-making frequently led to erroneous decisions with dire consequences. Reported human factor error included failure of flight crews to effectively manage resources, plan for contingencies, question authority, and request clarification [12]. Whether or not human error resulted in a consequential accident depended largely on the environment in which the error occurred—as an example, the authors point out that an altitude error is more likely to result in an accident when the plane is close to the ground. Furthermore, errors were found to be more consequential if they occurred during periods of high workload or nonroutine operations [12]. In contrast, technical problems including aircraft malfunction and equipment failures were comparatively rare and, in general, had a less significant impact on aircraft accidents. Billings concludes:

> The disease or disorder called "human error" causes half of the preventable deaths in both civil and military flying personnel. It is the largest single cause of premature mortality in this population. This disorder needs to be attacked as aggressively and effectively as we have attacked the physiological and medical disorders responsible for the remainder of preventable deaths [12].

The development of pilot training programs targeting human factors can be traced back to a 1980 NASA workshop entitled *Resource Management on the Flightdeck* [15]. Research presented at this conference explored the human and team behaviors most frequently implicated in air crashes. Key targets of cockpit team performance included interpersonal communication, decision-making, and leadership [16]. The term "cockpit resource management" (CRM) was created to refer to nontechnical (i.e., human resource) cockpit team training that focused on these specific aspects of human and team behavior [17]. CRM training was touted as an important tool to reduce the incidence of consequential aviation mishaps occurring as a result of human error.

Following the NASA workshop, and in response to recommendations made in the wake of the Tenerife investigation, aviation and aerospace moved quickly to develop CRM-based team training programs tailored to suit specific industry needs. Since that time, CRM training has undergone a significant evolution as it became integrated into the fabric of aviation safety culture and cockpit training. First-generation CRM programs mainly used seminar and tabletop exercises to engender elements of effective managerial style and professional behavior in the cockpit. More recent iterations have cut a broader and more inclusive swath, using realistic flight simulators to address human factor training in the context of simulated missions [16]. Third and fourth generations saw simulation-based line-oriented flight training (LOFT) become a required component of pilot training and expand its scope to include flight technicians, attendants, and mechanics in an attempt to engender common attitudes towards safety across disciplines [16]. Although each generation has had demonstrated successes in influencing flight crew's attitudes towards human factors, LOFT training has had the most robust impact on achieving buy-in from participants by producing demonstrable changes in behaviors observed during formal Line Operational Evaluations (LOE) of crews in full mission simulation [17]. The Federal Aviation Administration (FAA) currently requires airlines to provide CRM and LOFT training for all flight crews, while still allowing for carriers to maintain a degree of flexibility in training under the Advanced Qualifications Program (AQP) [1, 18].

A common thread spanning generations of CRM training is the notion that its primary goal should be to reduce the incidence of consequential human error through focused instruction on effective communication, leadership, resource utilization, problem-solving, and situational awareness. Helmreich, Merritt, and Wilhelm have argued that even when these specific behaviors are being taught, the link between human factors training and error management needs to be explicitly drawn, such that CRM is regarded as a series of countermeasures with three lines of defense: the avoidance, capturing, and mitigation of error and its consequences [16]. In this framework, error is regarded as "ubiquitous and inevitable," and instruction is refocused on the natural limitations of human ability, the nature of cognitive errors, and the effects of stress, fatigue, and work overload on team performance during both routine and crisis situations.

Proponents of CRM have pointed to a gradual but distinct decrease in airline incidents and fatalities occurring as a result of human error over the past 25 years as evidence of the effectiveness of formal team training to improve safety in aviation. However, aviation incidents are extremely rare events, and drawing specific conclusions about the impact of training in the accident rate per million flights is problematic [16]. Proposed surrogates have included direct observation crew attitudes and behaviors using formal LOE protocols. In the absence of a criterion standard for evaluating performance, it is not possible to say with certainty that CRM training, rather than advances in technology or "smarter planes," can account for the bulk of safety improvements. Nevertheless, based on the strong face validity of CRM principles, the majority of aviation crews believe that CRM training has had a significant impact on flight safety [19].

In 2001, Salas, Burke, Bowers, and Wilson published a review of 58 reports of CRM training in search of evidence for its effectiveness in preventing consequential error in commercial and military aviation [13]. Drawing extensively from the framework for evaluating training programs developed by Kirkpatrick [20], Salas and colleagues argue that while there is reasonable evidence that aviators enjoy CRM training and learn about CRM as a result of LOFT and other programs, evidence of a demonstrable impact on outcomes measured in terms of organizational outcomes is nearly nonexistent. Although simulation-based LOFT and LOE do generally demonstrate that CRM training has an impact on behavior, the link between improved cockpit dynamics in a simulated environment and safety outcomes in the real world remains by in large theoretical. The most powerful reports are those that assess the impact of CRM training on multiple levels and include higher levels of evidence (i.e., influences behaviors and outcomes) in their analysis—not surprisingly, there is a paucity of such multilevel reports in the literature, yet these studies generally offer the most compelling evidence that CRM training can have a broad impact on attitudes, knowledge, behavior, and outcomes [13].

Overall, the weight of evidence suggests that CRM training programs do offer something of value in promoting safety and human factors in aviation, and there is a general belief that human factors training does contribute to "safety in the skies." However, as Salas and colleagues point out, larger and more rigorous multilevel studies are needed in order to accurately assess the impact of team training on aviation safety.

CRM in Medicine: Principles, Limitations, and Frontiers

Although the Institute of Medicine's condemning report on the consequences of medical error was published in 1999, medicine and in particular anesthesiology had been investigating ways to adopt elements of aviation team training as a tool to combat error in the operating room (OR) for more than a decade before the report was released. Several investigations into the causes of OR catastrophes have confirmed that at least half of critical incidents are caused by human error [21, 22]. In the late 1980s, David Gaba, Steven Howard, and a team of researchers at the VA Palo Alto Health Care System at Stanford University began to experiment with the use of high-fidelity human patient simulators as a tool to teach aviation-style team training to OR staff [4]. The result was Anesthesia Crisis Resource Management (ACRM), a simulation-based instructional paradigm for OR staff that focused on teaching principles derived from aviation CRM; leadership, problem-solving, situational awareness, communication skills, and resource management are still at the forefront of present-day ACRM protocols [23].

ACRM places participants in a realistic OR environment, complete with monitors, alarms, scrubs, drapes, and actors playing OR team members—the "patient" is a full-sized computer-operated human mannequin capable of reproducing realistic physiologic responses to procedural (i.e., intubation) or pharmacological interventions (i.e., induction of general anesthesia). A skilled simulation technician, who observes the scenario and programs responses from an adjacent room, controls mannequin responses. Gaba and his group developed and utilized the CASE (Comprehensive Anesthesia Simulation Environment) simulation system, created specifically for the purpose of investigating human performance, to faithfully reproduce a wide variety of OR crises, observe participant behavior, and provide instruction via focused debriefings using videotaped recordings of the crisis event as a stimulus for discussion with a skilled facilitator [24]. In many centers, anesthesia staff, residents, nurses, and even medical undergraduates now participate in ACRM training using high-fidelity simulation [24–26]. ACRM instruction and evaluation principles have been adopted for a multitude of disciplines across medicine, from radiology to critical care and emergency medicine [27–30]. Although these applications differ in structure and design, the basic elements of CRM training are similar:

1. Leadership: an effective leader stands back and manages the team, avoids authority gradients by listening to and accepting input from the team, and demonstrates prompt and firm decision-making.
2. Situational awareness: maintaining a "big picture" perspective—avoiding fixation error by actively reassessing and reevaluating the situation.
3. Communication: closed-loop communication (i.e., give an order/confirm its receipt/confirm its execution).
4. Resource utilization: mobilizing key human and equipment resources, asking for help.
5. Problem-solving: demonstrating an organized approach, thinking "outside the box," and rapidly implementing solutions.
6. Team-based behaviors: mutual support, adaptability, role clarity, cross-checking.

Effective ACRM training programs are based on three crucial tenants, as endorsed by Gaba: knowledge (understanding key team training principles), practice (the ability to use the simulator to safely practice team training skills again and again without threat of harm to patients), and recurrence (the need to repeat CRM training over time to combat skills decay) [31].

CRM is not a one-size-fits-all intervention—effective team training strategies need to be adapted to suit the operational, knowledge-based, cultural, and skills-based environment unique to each medical discipline [6]. To that end, many disciplines outside of anesthesia have taken or made initial strides towards the development of targeted team training interventions, including emergency medicine, critical care, and more recently trauma [6, 32–35].

Human Factors in Trauma Care

What evidence is there that CRM training has had an impact on patient safety in trauma? As is the case in aviation, the answer is not easily arrived at. Numerous studies are available demonstrating the impact of CRM-type training on knowledge and attitudes of health-care professionals. Simulation-based CRM training paired with focused debriefing has been shown to be effective at improving team communication [36], fostering positive attitudes towards team training [19, 33, 34], and enhancing team performance in a simulated environment [6, 33]. To date, there is a paucity of evidence to support the notion that CRM training has an impact on patient safety and outcomes [37–39]. In 2010, Capella et al. [40] were able to demonstrate that structured trauma team training based on TeamSTEPPS [41], human patient simulation, led to significant decreases in time from arrival to computerized tomography scanner, endotracheal intubation, and operating room.

While there is a clear need to evaluate the impact of team training on patient-centered outcomes, the cumulative evidence to date along with the strong face validity supports the continued pursuit of structured, high-quality human factor training as a mechanism to promote patient safety and reduce consequential error in the trauma bay.

Key Points

- Crisis resource management (CRM) training consists of a training program to improve leadership, situational awareness, communication, resource utilization, problem-solving, and team-based behaviors.
- While it is difficult to establish a clear link between CRM training and patient outcomes, it has strong face validity and has been proven effective at improving team communication, fostering positive attitudes towards team training, and enhancing team performance in a simulated environment.

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3 Leadership Theories, Skills, and Application

Sandy Widder, David Kolthoff, and Peter G. Brindley

Background

Trauma can be an environment of chaos. As such, meaningful leadership skills are required to keep patients safe and to optimize outcome. Resuscitating the trauma patients can be particularly demanding. This is due to the concomitant stress of rescuing unstable multi-injured patients, and the needs of a complex multidisciplinary team. Without structure, a stressful climate can lead to inadequate leadership (i.e., nobody in charge or inadequate role clarity) or dissonant leadership (i.e., somebody *is* in charge, but their style is inappropriate to the situation or team structure). Therefore, poor leadership can exacerbate rather than mitigate a difficult situation, and patients pay the price. Accordingly, Hjortdahl et al. identified 'leadership' as the most essential nontechnical skill for a trauma team to be successful [1].

A growing body of literature (along with experience and common sense) suggests that focusing on team-training and leadership pays off. For example, Thomas et al. studied pediatric residents, undertaking a common neonatal resuscitation program, but provided deliberate team-training to only half. This single intervention was associated with increased information sharing, inquiry, assertion, vigilance, and workload management. Other studies have similarly concluded that team structure matters and that better leadership improves team performance [2–5]. Accordingly, courses that previously focused on factual knowledge are now including modules on teamwork and leadership. This includes the American Heart Association and their Advanced Life Support and Pediatric Advanced Life Support courses [6, 7]. In short, if teamwork was a drug, we would insist that our patients received an adequate dose, and in a timely fashion.

Leadership cannot be assumed but can be taught. Moreover, there is growing evidence that virtual and simulated environments are particularly well suited to addressing leadership and other related nontechnical aspects of resuscitation (situational awareness, role clarity, communication, and collaboration). The cumulative literature demonstrates substantial improvements in critical treatment decisions, less potential for adverse outcomes, and improved team behavior and efficiency [8–10]. Improved team performance is associated with more timely treatment, which in turn is associated improved trauma outcome. Moreover, leadership and team skills can also be taught regardless of seniority. For example, in a study by Ten Eyck, medical students who received simulation training had an improvement in clinical decision-making, communication, and team interactions [8].

Understanding Good Leadership

While "good leadership" can be difficult to define, most of us recognize it when we see it (or lament its absence when we do not). Regardless, most definitions of "good leaders" include someone being able to manage the entire situation (people, tasks, distractions), someone who is prepared to take responsibility ("okay, I'm taking over, listen to me"), and someone who is empowered to make definitive decisions (the buck stops here). Specifically in trauma, Klein et al. reported that "effective" leaders performed at least four key functions: strategic direction, monitoring the progression of clinical care, providing hands-on treatment, and teaching

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other team members (not only pertinent facts and procedures but also leadership attributes) [11].

Notably, the terms "leadership" and "management" are used interchangeably (both within medical and organizational literature). However, there are subtle differences. While leadership and management skills overlap—and one without the other can spell disaster—[12] leadership is more precisely defined by personal characteristics and how those attributes affect relationships. In contrast, management refers more to the functions and logistics of the larger team. Notably, the Advanced Trauma Life Support course teaches a useful, universal, and reproducible approach to trauma. However, this otherwise excellent course focuses on individual and technical competencies rather than how to work within or lead a high-performing team.

There are as many leadership styles as there are leaders. However, presumably all good leaders share a singular goal: to guide a group, team, or organization towards a common goal [13]. A recent publication [13]—based on Lewin, Lippit, and White's 1939 work—outlined three archetypal leadership styles: autocratic, democratic, and laissez faire. The authoritarian, or autocratic leadership style, exemplified clear expectations and obvious division between leader and follower. This leadership style was efficient but rarely fostered creativity within the larger group. Democratic leaders participated *within* the group and acknowledged input from members. Despite less productivity from the democratic group (compared to the autocratic group), the contributions were of higher quality. Therefore, the democratic leadership style was believed to be the most effective. However, hierarchy still matters and democracy can go too far. The laissez faire, or delegation group, was the least productive. Decision-making was least likely because the group was unstructured and not empowered. Seventy-years on, it is noteworthy that these archetypal leadership styles are still recognizable to modern healthcare workers.

The autocrat seeks little input and leads by control. This has been called a "transactional relationship" and relies upon rewards and punishments. This in turn depends upon obedience of subordinates. In contrast, a "transformational relationship" relies upon engagement and has a flatter authority gradient. This approach includes the need to inspire and motivate, create a shared vision, and foster collective ownership. The acuity of trauma can make it hard to find time for the tact and preemptive engagement required for transformational relationships. However, this only emphasizes the importance of anticipatory team building (including that gained from regular simulation) and the dexterity required of the modern team leader (see below). Bass introduced the term transformational leadership in the 1980s. Accordingly, it has also been called visionary or inspirational leadership. While it clearly requires more effort (including prior to the trauma even occurring), it offers a useful goal for the modern trauma team [14].

Qualities of a Good Leader

In addition to the above, it has been argued that leaders also need to be self-aware, self-assured, and self-confident. This needs to be tempered by emotional maturity, integrity, and acknowledgment of the team's needs [13]. Effective leadership traits have also been summarized in five broad categories [15, 16]. These "Big Five" include assurgency (extroversion), conscientiousness (dependability), agreeableness (affiliation), adjustment (emotional stability), and intellectance (open minded). 'Assurgency' would allow for someone to speak their mind. This is especially helpful in those trauma resuscitations where members are unfamiliar with each other's working styles, or inexperienced in general. 'Conscientiousness' speaks to maintaining a high degree of accountability and ethical standards. This in turn could positively affect patient outcomes in trauma resuscitation. Agreeableness would promote cooperation and bonding within the team. 'Adjustment' would allow for emotional neutrality which is crucial in high stress situations. In contrast, when the leader leads in an erratic manner, a potentially calm resuscitation can spin into chaos. 'Intellectance' allows flattening of the hierarchy and promotes input from others. This allows for varying perspectives; which is crucial if the trauma team leader is struggling to find solutions: (i.e., why is this patient still in shock?) Specifically in trauma, Andersen et al. concluded that a leader was someone who communicated effectively, delegated tasks, was clinically proficient, and was able to plan and prioritize [17]. Similarly, Cole and Crichton defined a leader as someone "who is responsible for team preparation prior to the patient's arrival, analysis of findings, development of a management plan, and coordination of patient referral to other specialists" [18].

Regardless of the adjectives used to describe good leaders, it is important to emphasize that leaders are more often made than born. Despite this, leadership skills are insufficiently addressed in traditional curricula. Therefore, we should not be surprised that many junior physicians are uncomfortable being in leadership positions, especially during resuscitations. Hayes et al. found half (49.3 %) of residents felt inadequately prepared to lead cardiac arrest teams [19] and over half (58.3 %) felt unable to lead an emergency department resuscitation [20]. In short, we need to do better. Fortunately, crisis resource management (CRM) (which includes leadership principles) can be taught and measured.

Strategies to Improve Leadership

There is a plethora of leadership styles, based primarily on personality traits, personal experiences, and situational context. The best leaders are flexible, and do not assume that one-leadership-style-fits-all. An effective leader can marry different leadership styles, based on the specific situation. The first step is self-awareness: recognizing your personality, how this affects your leadership style, and how you react to stress. For example, do you tend towards hinting, encouraging, or ordering? Is your natural approach to praise, admonish, or say nothing? Do you possess the flexibility to alter your style depending upon the acuity of the situation and the composition of the team? When there is little help or little time, an authoritative style is probably required [11]. When patients are more stable and when senior help is available, a more collaborative approach is typically better. In short, a good leader is dexterous with more than just their hands. A good leader knows how to individualize leadership style just as clinical therapy is individualized.

Leadership cannot be assumed: it needs to be earned. This is because team members need to trust their leaders. However, as outlined above, trust usually takes time. In contrast, trauma care is notable for its immediacy. Therefore, team leaders need to rapidly demonstrate their communication and leadership skills. All of this is done while focusing on patient needs, minimizing adverse events, being aware of the big picture, understanding the available resources, and directing the priorities. In other words, trust is not automatic, but nor should it be automatic given the complexity of trauma care. Once earned, leaders are empowered by the team to be decisive and, when necessary, to override others. In return, leaders should make the team feel safe to speak up. They do this by demonstrating that others' contributions are valued [21].

Medical doctors (whether surgeons or physicians) are typically expected to lead a priori. However, the best teams know to include all team members and not to discount the leadership abilities of senior nurses or allied health. As outlined, the highest functioning teams are dexterous enough to modify their structure, hierarchy, and communication norms to an individual problem [22–25]. This means that good leaders are also responsible for creating the right team culture no matter what the clinical particulars. This culture focuses on "what" is right, not "who" is right. In this way, the right leadership style also promotes a culture of safety and perpetuates a culture of teamwork [23, 26].

Aviation research shows that in a crisis, 10 % of people will lead, 10 % will freeze, and 80 % will neither lead nor freeze … but can be led [25]. As a result, hierarchy remains a key strategy to combat confusion and complexity [23, 27]. However, for every strength we gain, we must mitigate a potential weakness [28]. For example, aviation crashes are commonly the result of subordinates not speaking up—even with their own lives at stake! [22, 24]. In contrast, without leadership, diffusion of responsibility can occur [23]. Some tasks—typically the easiest—will be addressed by several people even though one would suffice. Other tasks—typically harder ones—remain undone [23]. Good leaders routinely change the focus between clinical task completion and team coordination [23]. This reduces fixation errors and prevents overtaxing individual members.

Encouraging team members to share information in a nonpunitive manner can increase team cohesion. However, how that information is communicated is important. One of the key features of CRM is utilizing closed loop communication (command, acknowledgement, report upon completion). This ensures that instruction are not only heard but understood, completed promptly, and that the team is updated in order to move to the new priority. Communication should be delivered in an assertive manner such that it is clear, concise, and has the appropriate sense of urgency. However, in order to maintain a functioning team, this communication should also be respectful and nonthreatening [29].

If clarification is required, and time allows, then the leader can further bolster teamwork by providing justification as to why this matters and why now. He/she can also alert the team about what to expect next. Again, aviation offers practical strategies that we can apply to trauma care. For example, pilots talk about "flying ahead of the plane" when they communicate proactively. Pilots also emphasize the importance of communication when they talk about "flying-by-voice" (rather than say "flying by instruments"). In other words, an effective leader likely "flies ahead of the patient" and "resuscitates by voice" as much as with his/her hands. For example, when a hypovolemic trauma patient is about to be intubated, the trauma team leader can prepare the team by saying "because of a decreased level of consciousness, we are intubating this patient. However, he is likely hypovolemic so may become hypotensive with positive pressure ventilation. Please ensure we have two units of packed red blood cells and a norepinephrine infusion ready." These strategies not only provide direction and structure, but may decrease doubt and anxiety to manageable levels [30].

As teams mature further, they will anticipate each other's needs and actions. Therefore, they are more likely to act and communicate more automatically (so-called implicit coordination), which, in turn, frees team members to listen more actively [23]. The more routine the task, the more experienced its members, and the more familiar they are with each other, the less explicit coordination is required. The more unfamiliar the task, or its members, the more that explicit coordination is required.

As outlined, a good leader is one who sustains his or her team. Therefore, even under stress, it is important to be professional and calm and maintain everyone's focus [31].

Team members can inadvertently create distractions, and leaders may need to prevent or manage conflicts at the same time as coordinating a complex resuscitation. As above, understanding conflict management includes understanding your own and others' personalities, and how they can interact both positively and negatively. We should also recognize how these signals might be amplified in a stressful environment. Flin has suggested the following self-help cognitive technique (STOPP technique) as a practical strategy [31, 32].

S—Stop, do not act immediately. Assess the situation.
T—Take a few deep breaths, pause.
O—Observe. What am I thinking? What am I focused on?
P—Prepare yourself.
P—Practice what works. What is the best thing to do?

A leader should take time to assess the situation, and not act on emotions alone. They should keep their emotions in check and understand why a particular reaction may be invoked. Also, it is important to try to understand the reaction of other members on the trauma team and not take any conflicts personally. If conflict continues, it is worth acknowledging the difference of opinion, but also reinforcing a congruent mental model. (e.g. "I understand both your points, but we all need to focus back on securing this airway"). However, this should not be overdone in a crisis. Typically, relationship conflicts should not be resolved during an emergency; but this is why debriefing is so important [23]. In contrast, task-related conflicts must be dealt with promptly, as patients can be at risk [23].

Good leaders also know that an inexperienced team can still function well, but typically need more direction [23]. This usually means more hierarchy and centralizing control [23, 27]. As the team matures, so should the team structure. The leader can now create a culture where members learn to volunteer relevant information, verbalize contingencies, and apportion responsibility (so-called explicit coordination) [23]. Once a culture of trust and safety is established, trauma teams should voice relevant concerns and ask critical questions. This "cross-monitoring," or "mutual-monitoring," is one way to flatten the team's authority gradient [23].

Conclusions

Poor teamwork can amplify a vicious cycle where patient care becomes ever more fractious. In contrast, great teamwork can create a virtuous cycle: where the teams become ever stronger. A leader has vision and the ability to inspire. However, leaders also have humility and realize that these skills are rarely innate and that they alone rarely have all the answers. Practice and insight can help create a culture of teamwork and safety… where patients are the ultimate beneficiaries.

Key Points

- Better trauma team leadership is probably associated with better patient outcomes. As such, teamwork truly matters.
- An effective leader is self-aware and adopts styles such as transformational leadership to inspire and motivate the team.
- Effective team leaders create a shared vision and can balance leadership and team maintenance.
- Leadership and crisis management go hand in hand. Leaders need to be flexible and individualize their approach. This depends upon the acuity of the situation and the composition of the team.
- Effective teams promote open bilateral communication and collaborate to create a climate of information sharing.
- Communication is the most important way to create and maintain a team. Attention to verbal and nonverbal communication is an essential skill in trauma resuscitation.
- A self-aware leader is able to identify and manage triggers that could otherwise derail teamwork. The ability to stay calm and professional, especially during stress, is key.

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Teamwork and Communication in Trauma

4

Peter G. Brindley

Introduction: Why Does Teamwork Matter?

The idea of directly translating ideas from aviation to medicine may have been oversimplified. However, the best healthcare worker will always be open to insights, no matter what their origin. This chapter offers well-developed crisis management strategies taken from other high-stakes professions, but applied to the modern trauma team. Evidence in the literature shows that inadequate teamwork (and inadequate communication) represents amongst the most common reasons for preventable error [1–6]. Despite many advances in surgical technique and patient care, trauma has been a latecomer to the study of human factors and team dynamics [1, 2]. This needs to change and we need to share the best ideas no matter what their source. Aviation offers readily available strategies regarding how we can make a "science of reducing complexity" and a "science of team performance" (see Table 4.1). In short, trauma training needs more "we" and less "me" [2].

In 1977, the largest aviation disaster (to date) occurred when flights KLM 4805 and Pan Am 1736 collided. Five hundred and eighty-three died. Investigators concluded that not only was the accident wholly preventable, but that a major cause was because the crews had "failed to take the time to become a team" [1]. In a similar vein, evidence shows that fewer planes crash when the copilot is flying [7]. There may be several explanations; however, most believe this is because, firstly, the senior pilot is unafraid to speak up and, secondly, because the subordinate is now actively involved [7]. In other words, an ad hoc team has formed with larger mental and physical capacity than previously existed. Evidence suggests the same for acute care medicine [2]. However, what our profession has been slower to realize is that team skills are not innate and therefore cannot be left to chance. In addition, these are nontechnical skills and require novel approaches such as simulation. As will be outlined, team skills encompass effective communication, adaptability, compensatory behavior, mutual monitoring, and the ability to give and receive feedback [2]. In short, modern trauma care is as much about "team dexterity" (and "verbal dexterity"—see below) as it is about traditional factual knowledge or procedural skills.

In 1935, after the crash of the B17 bomber during a test flight, it was lamented that "the modern plane is just too much for one man to fly" [1]. Similarly, the complexity of trauma care makes the modern patient simply too much for one clinician to manage. In fact, the modern critical care unit patient has been estimated to require approximately 180 steps per day [1]. Regardless of the exact number, clearly such complexity exceeds even the most capable individual. Therefore, it is not hyperbolic to argue that without effective teamwork high-quality trauma care is largely impossible [2].

What Does It Take to Create a Team?

Teamwork, which can be defined as "cooperative efforts to achieve a common goal," is more than just subordinates doing as the leader tells them [2]. Instead, it is about maximizing the mental and physical problem-solving capabilities, such that the sum exceeds the parts [2]. In addition, task demands (rescuing the patient) and social demands (running the team) have to work in parallel [2, 8]. Expressed another way, we need strategies to turn individuals into team players, or else the team fails and the patient pays the price. Individual team members will not share their abilities unless they feel "safe" to do so [2]. This does not mean that we no longer need leaders and leadership qualities. However, it does mean that we cannot create the teams that we want unless we create the culture that we need [8].

Culture is a complex whole that includes the knowledge, beliefs, customs, and habits possessed by a group. It is a powerful influence upon behaviors, attitudes, and actions [8]. Traditionally, medicine has a laudable culture that

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Table 4.1 Practical strategies to improve team work in a medical crisis

Team factor	Recommendation
Climate and culture	• More "we" less "me" • Mutual respect; calm and decisive • Hierarchy still has a role • "What" is right, not "who" is right
Establish structure	• Assign roles • Assign responsibilities • Establish priorities • Communicate throughout
Create shared mental model	• Ensure all are on the "same page" • Invite input when possible • Outline priorities • Set emotions of the team
Cross monitor	• Monitor performance • Monitor workload • Flatten hierarchy • Encourage feedback
Maintain resilience	• Routine practice sessions • Request feedback • Encourage debriefing • Provide time for casual interaction

includes patient ownership and self-reliance. However, we typically focus on the individual agenda rather than the cohesion of the team [2]. We also presume that success results from individual efforts (and failure from individual shortcomings), rather than advantages proffered by the culture or environment [2]. As a result, quality care has been historically linked to how the solo practitioner performs, and remedies have focused on individual competence [2–6, 9]. This needs to change.

In addition to accepting the need for teamwork, we also need to perfect the team structure. The most common team failings (and therefore the areas on which to focus our resources and energies) are the inability to assign roles and responsibilities, to hold team members to account, to advocate a position or a corrective action, to use checkbacks (i.e., "closed-loop communication"), to seek usable information (as opposed to just "data"), to prioritize tasks, and to cross monitor other team members [2]. In short, a team of experts is not the same as an expert team [2].

Teamwork: Good and Bad

Teamwork is probably the best way to mitigate task overload and fixation errors. However, not all teamwork is inherently good. As a result, psychology also offers useful cautionary tales for the modern physician. Zimbardo's infamous Stanford prison experiment (which had graduates students assume the roles of prisoners and prison guards) demonstrates how easily we can be made to assume roles even when not beneficial. Even though play acting, the students quickly formed into two teams, with one becoming excessively unruly (the prisoners) and the other excessively sadistic (the guards). In a similar vein, Stanley Milgram's work (where he was able to get people to administer electric shocks to others) further demonstrates our propensity to blind obedience [10]. Solomon Asch's experiments (where he could get experts to give incorrect answers just by having other confederates answer incorrectly beforehand) show how easily we can be made to do things that we know are wrong. Of note, in Asch's experiments there was no overt coercion, merely the power of embarrassment and social conformity [10].

The apparent irrationality of modern man and his (or her) blind spots is tough for some professionals to accept [8]. However, humans have evolved as social beings and are therefore highly susceptible to social pressures [2, 8]. This will be explored in more detail in Chap. 5. Regardless, it should not be surprising that we resort to behaviors that have worked well for most of our evolutionary past, especially during a crisis [8]. Accordingly, good team leaders know to capitalize on the best of our primitive crisis behavior and mitigate against our innate shortcomings. For example, good leaders can capitalize on our propensity to obedience during a crisis. At the same time, good team leaders realize that too much hierarchy will suppress the team's larger cognitive capacity [8].

Insightful team leaders should know that once a majority of team members have formed an opinion, they usually stick with it despite contradictory information [2]. This is done subconsciously to reduce a sense of isolation and of "cognitive dissonance" (the discomfort that humans have with holding two or more contradictory ideas simultaneously) [10]. As a result, a good team leader will deliberately and routinely challenge assumptions (why are you so certain this is hemorrhagic shock?). In a similar vein, "group think" means that teams may follow the majority opinion rather than the rational argument ("if we all agree, then we can't be wrong") [2, 10]. As a result, the good team leader will force the team to seek out contradictory information ("I still want to see that ECG before we take this patient to the operating room"). Interestingly, teams can also amplify individual behavior. For example, groups tend towards greater risk if an individual's initial tendency was to be risky and towards more caution if individuals were risk averse [2, 10]. Team behavior can (and must) be managed and is a key leadership skill that can be taught.

Team Leadership 101: The Shared Mental Model

Leadership includes providing structure to chaos and organization where previously there was none [8]. A key strategy is the "shared mental model" (a common understanding, or, in colloquial terms, a sense that everyone is "on the same page") [2]. This helps to form a task-focused (rather than power-focused or ego-focused) team as well as a structure to prioritize duties,

Table 4.2 Practical strategies to improve verbal communication in a medical crisis

• Perform regular simulation exercises
• Practice active listening
• Model "transmitter-oriented language"
• Ban "mitigating language"
• *C*ite names; be *c*lear/concise; *c*lose the loop (3 *C*'s of communication)
• Structure communication using "SBAR" and "repeat backs"
• "Call out" when significant changes occur
• Practice "escalating assertiveness"
• Avoid "somebody"/"anybody" comments
• Respect communication "sterility"; control interruptions

manage information, establish roles, stabilize emotions, and build confidence [2]. If time allows, then the team leader should invite members to suggest a mental model ("What do you think? What should we do?"). After all, diverse inputs can provide the team with a more comprehensive view [2, 8]. However, under time pressure, the leader has to rapidly establish a reasonable mental model that members will support ("I believe its hemorrhagic shock; please do the following") [3]. Studies have shown that the best situational awareness and the shortest reaction time come from practice and prior exposure [8]. As a result, we should look to regular simulation as an important (and safe) team-training tool. In this way, simulation is a great way to develop team "reflexes" and for leaders to learn the power of the "shared mental model."

The greater the overlap in shared mental models, the more likely that team members will predict, adapt, and coordinate, even if dealing with stress or novelty [2]. It is also essential to regularly update the shared mental model ("okay, the airway is secured; our next priority is…") and to ensure that it still makes sense as new knowledge comes to light ("I now have an ECG that shows ST elevation—please listen up because things have changed"). Task assignment is usually specified by profession (e.g., anesthetists intubate and surgeons operate) [2]. Therefore this does not usually need to be negotiated in the mental model. However, if there is confusion (i.e., both the anesthetist and surgeon could insert central lines), then the good leader predicts that it may cause confusion and hence that it needs to be explicitly stated ("Dr. Smith, you intubate; Dr. Jones you do lines"). In short, the mental model must be clear, proactive, and flexible (Table 4.2).

Say What You Mean and Mean What You Say

Mounting evidence shows that ineffective communication during an acute medical crisis is one of the commonest reasons for preventable medical error and preventable death [3, 7, 11]. This should not be a surprise; after all we have long known that poor cockpit communication—especially between junior and senior crew—is one of the commonest reasons why mechanically sound planes crash [3, 7, 11]. It is also time to understand that our "verbal dexterity" is every bit as important as factual knowledge or procedural dexterity during a crisis [3]. Most of what follows is not native to medicine. Fortunately, it is highly translatable to our reality.

Many shortfalls in communication can be summarized using the following pithy quote by Rall and Gaba: "Meant is not said; said is not heard; heard is not understood; understood is not done" [12]. However, it is also important not to oversimplify something as complex as communication. For example, communication is far more than just talking. Communication aids task execution, enables information exchange, and helps (or hinders) relationship building [2]. Communication is also more than just what is said. It also includes how it is said and how it is understood [2]. As a result, nonverbal communication (which includes posture, facial expressions, gestures, and eye contact) as well as paraverbal communication (which includes pacing, tone, volume, and emphasis) are at least as important as verbal communication [2, 11]. This is especially true when there is incongruence between the words used and the facial expression or the tone [10]. As a result, while this section will present several practical verbal techniques (again borrowed from aviation and adapted to medicine), we are only scratching the surface. Readers are strongly encouraged to read more and to realize that expertise in acute trauma means expertise in all facets of crisis communication [2, 3, 11].

Flight investigators have made flattening the authority gradient a priority [7]. One way to do so is to mandate more "horizontal communication" [7, 11]. This means that all members of the team are authorized (in fact obligated) to speak up and to do so clearly, regardless of rank [7]. Moreover, aviation has mandated "transmitter-orientated" communication (where it is the speaker's responsibility to be understood), rather than "receiver-orientated" communication (where it is the listeners responsibility to unravel what was meant) [7]. However, making communication more deliberate means that we also promote active listening [2]. This requires that we confirm understanding and demand clarification, regardless of seniority or embarrassment [2, 4, 5]. In short, all team members take responsibility for how messages are delivered, received, understood, and carried out [2, 3, 8, 11].

Crisis Communication 101

A common feature following aviation crashes is black-box silence for minutes before a crash [3, 7]. Similarly, ask most nurses about the last bad resuscitation they witnessed and it is likely notable for the same thing: silence despite chaos. Therefore, team members need to be taught strategies regarding how to speak up [3, 7, 11]. Physicians may not speak due to stress or uncertainty or simply because they do not have the usable lines [13]. For example, instead of silence, we can teach the leader standardized verbal responses. An example would be "we still have no pulse…what am I missing?" Another would be "I am unclear what happened before we arrived; who can summarize?" [3]. Other team members need verbal strategies to become part of the trauma team rapidly. An example could be "I am from General Surgery; is there any job that needs doing?" Just as teamwork does not come naturally nor does crisis communication. Again, simulation is an ideal tool. It enables us to discover what works and to master what are, after all, life-saving skills.

The military and aviation have used *SBAR* (Situation, Background, Assessment, Recommendation) in order to provide a recognizable structure to communication. While it may seem overly formal—especially when team members are either familiar with each other or if the problem is routine—it can offer a very useful construct for junior staff and for unfamiliar situations [14]. A simple example could be the following: Situation: "this is Dr. X; I need your help right away"; Background: "he's a 35-year-old with a blunt splenic injury"; Assessment: "he is still hypotensive despite four units of blood"; Recommendation: "You should review him now regarding need for surgery" [3, 14].

In addition to getting aviators to speak up, they are also taught how to be acknowledged and how to be taken seriously. Therefore, they learn how to use levels or grades of assertiveness [2, 3, 7, 11, 13, 15–17]. For example, Robert Besco's iconic four-step PACE communication progresses from probing to alerting to challenging to emergency language [17]. Other constructs include up to six steps. Regardless, the intention is to offer strategies from least to most direct. For example, this includes the "hint" (e.g., "should things look like this?"), "preference" (e.g., "I would suggest…"), "query" (e.g., "what do you think?"), "shared suggestion" (e.g., "you and I could"), "statement" (e.g., "we need to"), and "command" (e.g., "do this now!"). Of note, those actively listening should also pick up on the escalating urgency and react accordingly. It is worth reemphasizing that leaders understand that crisis communication is as much about listening as talking.

Without instruction, junior team members may only hint and, if ignored, fail to escalate their assertiveness further [7]. On the other extreme, without instruction, senior team members may rely too heavily upon blunt "commands" [7]. This style is certainly unequivocal and is needed when team members have repeatedly failed to appreciate the seriousness of a situation. However, it can destroy the team structure if routinely used as the initial, or the only, communication style [7]. With the same purpose in mind, aviation also teaches a five-step model of advocacy and confirmation [13]. The following includes aviation examples and medical corollaries: "Attention Getter" ("Captain/Doctor"), "State Your Concern" ("We're low on fuel/the patient is hypotensive"), "State the Problem as You See It" ("I don't think we can land/I think we need to operate now"), "State a Solution" ("Let's re-route to a closer airport/I'll book the OR theater"), and "Obtain Agreement" (e.g., "Okay, Captain/Doctor?") [13].

Applying the "C's of communication" means that we must *cite* names (to avoid diffusion of responsibility), that we must be *clear* and *concise* (to avoid confusion), and, most importantly, that we must *close the loop* (to confirm that it has been done) [3–5, 11, 13]. This means that we reinforce our instructions by demanding verbal feedback. For example, we tell a specific person to intubate but also to tell us when it is done (or to tell us the end tidal CO_2). This also means we do not just ask for two units of blood but rather "Nurse, give two units of blood…and tell me the blood pressure when it is in" or "Jim, poke for an arterial blood gas…and bring the result back to me." In other words, there are many ways to "close the loop," but as a strategy, it confirms that the instruction was heard, understood, and done. A potential additional C includes "crowd control." This means ensuring that there are enough people present ("we do not have someone who can do a surgical airway; go and get me Dr. X"), or that we have the right people present ("please tell me your role") or that we do not have too many people present ("thank you for responding, but we need to clear out all but the following people…").

Another strategy is the "call out" [13]. This means that we alert the team whenever there are important changes ("he's starting to go back into ventricular fibrillation") [13]. Similarly, the "step back method" means we verbally force a "time-out." This compels the team to reassess their assumptions ("stop chest compressions; we need to know if we're still in asystole"). The "repeat back method" [13] provides a safety check by repeating in order to confirm mutual understanding ("so was that one full mg of epinephrine?"). The "read back method" [13] means we confirm a verbal order before processing it ("okay, so first you want two packed cells, then repeat a hemoglobin, then call you if it has not increased").

While team members must be encouraged to speak up, they need to be taught how to make those inputs task focused and appropriately timed. If not then it can further exacerbate the cacophony and chaos [2, 8]. Non-helpful interruptions are considered such a safety hazard in aviation that they are now addressed in this industry's standard operating procedures. The "Sterile Cockpit Rule" means that no non-operational talk is allowed during critical phases such as taxi, takeoff, or landing [11, 18, 19]. Of note, it applies to all those in the cockpit to enforce it, not just those currently talking [11, 18, 19]. We understand the need for microbiologic sterility in surgery, so why not "communication sterility."

The Sterile Cockpit Rule [18, 19] can be readily adapted to medical practitioners during resuscitation [3, 8]. In less-critical situations, we should confirm if others are able to focus their attention ("I want your opinion; do you have two full minutes?") [3]. In more-critical situations, we can demand attention ("I need you to stop that conversation and focus on this critically ill trauma patient"). As was pointed out to me by a wise resident colleague, the anesthetist is in his or her critical phase during induction and awakening. Therefore, the surgeon must avoid unnecessary noise or distraction. Once the operation is under way, the surgeon is now in his or her critical phase even if the anesthetist no longer is. It is now just as important for the anesthetist to avoid unnecessary interruptions or disturbances to the surgeon. In other words, all members are responsible for creating the right environment so that the right team communication can be leveraged to benefit the patient [3, 11].

Ambiguous or noncommittal speech (aka "mitigating speech") is common prior to airline crashes, as well as during medical crises [7]. This is why, during crises, we must replace comments like "perhaps we need a surgeon" or "we should think about operating" with "get me a surgeon" and "we need to go to the operating theater, now." Junior members (or those that feel "unsafe" in their role) may mitigate speech to show deference, when embarrassed, or if unsure [2, 3]. Interestingly, if time permits, then "mitigating language" can be harmless and may aid team building ("if you get a moment, could you help me with this patient?"). However, if the wrong communication tool is used during a crisis, it can be no less dangerous than the wrong surgical instrument. It is about being as dexterous with your communication as with your hands.

Overcautious language is inappropriate during crises, just as overly strident language can be inappropriate at less-critical times. Crisis communication should still be polite, but must be unambiguous ("John, your next job is to intubate; do it now, please"). Communication must also be addressed to a specific person to avoid diffusion of responsibility [2, 4, 5]. This is why comments like "could someone" and "does anybody" are inappropriate [2]. However, just as we need to control communication during a crisis, we need to loosen the reigns once it has abated. As a result, at other times we also need to promote more free-flowing communication. This is essential for debriefing, conflict management, and stress relief. In other words, communication is also essential to keep the team resilient ahead of the next crisis [2].

Conclusions

Despite a culture that typically trumps the individual, modern medicine (and especially acute care medicine) demands teamwork and team communication. In addition, it requires team leaders who understand the basics of human psychology and how this can be utilized to the patient's benefit. Practitioners, educators, and administrators should agree that teamwork must not be assumed or left to chance. Instead, teamwork should be deliberately taught and routinely practiced. We also need to adapt, and then to freely share, the best strategies learned from other high-stakes professions (and from each other). In other words, readily available strategies do exist. The question is whether we have the requisite humility and insight to evolve.

Key Points

- Nontechnical skills likely have the greatest impact upon patient safety and outcome.
- We must make a "science of reducing complexity"—fortunately practical strategies can be taught.
- Teamwork is key to reducing chaos and complexity.
- Communication is the key leadership skill.
- Good teamwork (and communication) cannot (and need not) be left to chance.

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Situational Awareness and Human Performance in Trauma

5

Peter G. Brindley and Arthur Tse

Introduction

As outlined in the previous chapter, the factors that determine outcome in a crisis are more social than technological and have more to do with behavior than with factual recall or procedural dexterity [1–10]. How we act in a crisis is more complex but also more ancient than most people assume. Our behavior is more influenced by psychology than simple rationality, and we are more psychological than logical [2]. Because we still resort to behaviors that served our evolutionary past, we need to know our "oldest personalities" [2]. We need to study the personality that often takes over in a crisis, rather than focusing on the one that exists in our relatively controlled daily life.

If an engineer wants to know if something is "up to the job," he or she pressure tests it [2]. The same should apply to trauma leaders and their teams. Our brains have evolved to do many remarkable things, but resuscitation is not one of them. Therefore, competence cannot be assumed, but can be taught and must be tested. Fortunately, our brains (and our teams) are malleable, and we can be "rewired." Thus, preparation and practice are important influences on how we will react and perform under stress. This chapter aims to provide applicable insights. After all, evidence shows that the most important variable in surviving a disaster is our behavior. In short, disasters are predictable, but the outcome is not [2].

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Situational Awareness

Broadly defined, situational awareness encompasses how we perceive relevant cues, how we comprehend their meaning, how we synthesize a mental model, and how we predict what should happen next [3, 4]. This requires an element of "metacognition"—namely, an awareness and understanding of one's own thought processes. This in turn provides insights into our cognitive strengths and weaknesses and therefore (hopefully) how to improve our problem solving (see Table 5.1) [5, 6]. Without reflecting upon how we think and act (especially under stress), the healthcare provider is more vulnerable and the patient more likely to pay the price [3–6]. Typically, situational awareness is divided into three levels, with each building on the one before [3, 7]. In the face of the information overload and the high stakes of acute care medicine, the ability to maintain situational awareness, to identify errors, and to take corrective action is quite literally lifesaving.

Situational Awareness: Level 1

The first level of situational awareness involves the perception of stimuli (otherwise known as "cues") [3]. Importantly, this requires the individual to focus their attention [5]. However, we must also realize that by focusing "here," we risk missing "there." In other words, we have finite attention. Because of the avalanche of stimuli, we must make conscious and unconscious decisions upon where to prioritize and what to ignore (or postpone). This can lead to fixation errors: where we focus our attention inappropriately and where we miss relevant cues. This is especially true during stress when we achieve a type of cognitive tunnel vision.

In moderation, tunnel vision lets us focus on what really matters (i.e., airway, breathing, and circulation) and eliminate what can wait (i.e., abnormal blood work). In excess,

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Table 5.1 Human factors associated with situational awareness and performance

	Benefits	Risks
Perception		
Scanning attention	Sample many stimuli	Stimulus overload
	Avoid fixing on one stimulus	Lack of prioritization
Focused attention	Prioritize	Fixation error
	Eliminate "unimportant" cues	Miss "important" cues
Synthesis		
Cognitive modeling	Recognize patterns (heuristics)	See patterns where they do not exist
	Reduce workload	Premature closure/confirmation bias
	Predictable response	Resistant to new ideas
Projection		
Anticipation	Predict future events	Incorrect assumptions
Sharing	Increased resources (cognitive/physical)	Need to coordinate a team
Stress		
	Increased vigilance	Exhaustion/overload
	Enhanced physical performance	Impaired complex thinking

we fixate inappropriately and miss what really matters (i.e., we commit a fixation error). Examples abound but include the cardiologist who only looks for cues of myocardial ischemia and therefore misses sepsis or pulmonary embolus or the internist who misses postoperative bleeding because he looks everywhere but under the dressing. Other examples are outlined below, but readers are encouraged to think of their own examples. After all, fixation errors appear to happen to practitioners of all specialties and levels. The difference appears to be that seasoned practitioners (hopefully) know the most deadly fixations and how to mitigate them quicker [5]. Additionally, it is more likely that seasoned practitioners had previously experienced fixation errors and have learned to increase flexibility and vigilance.

For those still unconvinced about our cognitive fallibility, an excellent book by Christopher Chabris and Daniel Simons reviews their famous psychological experiment (aka "the invisible gorilla") [8]. In brief, Simons produced a video where viewers are asked to simply count basketball passes between actors wearing white and black shirts. Given the complex things that most professions do in their daily jobs, this may seem elementary. However, regardless of seniority, typically only half are correct. This is because the others were distracted by an actor who walks into the video frame midway through. He is wearing a gorilla suit and spends 8 s pounding his chest. Typically, viewers see either the gorilla or get the number of passes correct, but rarely both. What is equally insightful is when the video is replayed, many refuse to believe that there was ever a gorilla on the original. In short, our attention is imperfect, but so is our insight. The excellent video demonstrates how we have blind spots in our vision (and in our judgment) such that we only see what we are primed to see. Our brains are prone to looking without seeing, but also to hearing without listening and to acting without truly thinking [8].

Situational Awareness: Level 2

The second level of situational awareness requires synthesis and is intended to increase comprehension [3, 9]. In other words, we fuse disjointed pieces of data (e.g., chest pain, ECG changes, elevated troponin) into a recognizable model (i.e., the diagnosis of myocardial ischemia) [3, 9, 10]. By creating a cognitive model, our brains can accelerate both our understanding and our action. In other words, the model provides a short cut or "heuristic" [5, 9]. This in turn allows for pattern recognition. Ideally, recognition of a model (i.e., a diagnosis or clinical syndrome) is how prior classroom knowledge (pathophysiology, pharmacology, etc.) is retrieved and applied. Because of the importance of visual and emotional triggers, a more reliable way to unlock and apply knowledge is through situational exposure: such as realistic simulation or extensive clinical experience.

Mental models are also useful because they reduce the individual's cognitive workload. This can free up scarce mental resources for other demands. However, once again, we need to be aware of the potential downside. Firstly, we may see patterns when they do not actually exist and are slow to recognize exceptions (i.e., we continue to rationalize a routine diagnosis by downplaying contradictory information). Secondly, all species conserve energy whenever possible. Pattern recognition and mental models make this easier. Unfortunately, subconsciously this means that we rationalize shortcuts and decreased effort. We need to be wary of our propensity to create overly simple models (so-called premature closure) when we actually need to continue searching for other explanations (e.g., the infection that fails to respond to antibiotics because it is an abscess that requires surgical drainage). We need to understand that in a crisis, vigilance and persistence are ever bit as important as traditional "cleverness."

The other downside of our desire to reduce cognitive workload is that it can make us resistant to change. For example, the "Semmelweis effect" [11] is the reflex-like tendency to reject new evidence or knowledge because it conflicts with established norms, beliefs, or paradigms (i.e., the "new" does not fit with our current mental model). This is named after Ignaz Semmelweis who discovered neonatal mortality could be greatly decreased by hand washing. Once we understand that our behavior is more "psychological" than "logical" [5], it is easier to understand why the medical establishment rejected and even mocked his ideas.

Situational Awareness: Level 3

The third level of situation awareness involves "projection," which in turn allows the individual or team to respond proactively [6, 9, 10]. Once a mental model is created, assumptions can be shared, and this allow for anticipation and planning. For example, without even seeing a patient whom you know to have a severe head injury, you can predict that they may need airway control. Moreover, it is reasonable to assume that the patient may become hemodynamically unstable and hence will need to be where experienced staff and advanced monitoring are available. In short, this patient will either need to be in an ICU or near to one, regardless of the specifics of their case. The need for anticipation and preparation is also why another high-stakes profession, namely, the military, talks of the eight p's of crisis management: "proper prior planning and preparation prevents piss-poor performance." Expressed another way, "failing to prepare is akin to preparing to fail." Regardless, it should be clear why situational awareness is one of the prime ways for individuals to safeguard the deteriorating patient; another is to maximize collective awareness by optimizing the team.

Crisis management is a team sport [5]. Therefore, we need team situational awareness. Obviously, each individual has his or her own experience and limitations. However, they must also know enough about each other's skills and limitations in order to perform in a unified fashion. Therefore, each individual needs to not only hone their own situational awareness but also appreciate others'. Like a Venn diagram, individuals' situational awareness must overlap in order to function together as a team [1, 9]. For example, following a trauma, as the primary survey is performed, the findings should be announced. This way all members have an equal opportunity to achieve the first level of situational awareness. Subsequently, each team member can then focus on his or her specific area. For example, the anesthetist evaluates the patient's airway and chest regarding airway capture and ventilation. The surgeon also examines the chest, but for typical surgical interventions such as chest drains or central venous lines.

As each team member builds an individual awareness, they report their findings and plans back to the team leader. The team leader then integrates these individual models into a shared mental model that summarizes the patient's current state (level 2 of situational awareness) and predicts their trajectory (level 3 of situational awareness). In this way, the team's awareness amplifies each individual's awareness. In short, the leader creates an environment whereall members feel safe sharing anything that adds to the team's ability to react.

Factors Affecting Awareness and Performance

Attention

During a crisis, the volume of stimuli will typically exceed even the most capable individual. In order to process information, the individual focuses attention on relevant stimuli [2, 5]. In a way, attention is like a searchlight—highlighting things that the individual can then either perceive as a cue (important for the cognitive model) or as noise (irrelevant at this time). As the complexity of a situation increases, the number of possible cues requiring attention also increases. Unfortunately, like the diameter of the searchlight's beam, our attention is limited. This can cause selection bias either because our attention is misdirected (toward irrelevant stimuli) or simply insufficient (not enough cues are collected) [5, 12].

Fortunately, we can mitigate our innate selection bias. For example, there are two main types of attention in nature, and both can be applied in acute care medicine. Firstly, there is the scanning vigilance typified by prey (where focus is routinely refocused from one area to the next) [13]. In other words, by constantly redirecting our attention and sampling different inputs, we reduce the likelihood of selection bias (and fixation errors) [3, 5, 12]. For example, during trauma resuscitation, we scan the trauma bay looking for cues that suggest patient distress. Just like lifeguards who scan the beach, we avoid looking at just one spot. However, when danger strikes, we need the second type of attention typified by the focused gaze of a predator [13] (or exemplified by the lifeguard ignoring others as he or she focuses on someone in possible distress). This is where nonessential stimuli are minimized and tunnel vision takes over [5]. This second technique avoids wasting attention. However, as outlined, its potential downside is the fixation error and the illusion of centrality (that nothing outside of our immediate attention matters) [2, 5].

In civilian disasters, a common three-phase survival arc exists: denial, deliberation, and decision [2]. Preparation (whether through simulation or experience) decreases denial, means you have already done the work of deliberation, and means you have a cognitive roadmap for decisive action. This is probably why emergency drills save future lives. This is also why survival following plane evacuations is consistently higher for those that watched the in-flight safety video and know their exit [2]. A related three-part model has been summarized by Leach et al. who stated that we respond to crisis either by "fight; flight or freeze" [14].

How our human brains respond depends greatly upon complexity and familiarity. So-called automatic responses occur immediately because responses are embedded due to simplicity or repetition [4, 7]. For example, once the surgeon has begun to tie a knot, the actual tying process consumes little of their attention. As such, attention is freed up [5]. "Simple decisions" (e.g., which intravenous fluid to order) occur when there are a few possible responses available. Therefore, subconscious choosing usually takes a second or two. "Complex decisions" (e.g., being presented with a cluster of symptoms that you have never seen before) take longer because there is no appropriate response in the personal database. A response has to be created, and this consumes additional precious time. Finally, there is the "inability to make decisions" where no behavioral schema exists and no temporary schema can be created [14]. This typically causes stress, panic, or even paralysis [2].

Stress

Stress is a common term in modern life, but can be difficult to define. It is usually understood be a state of psychological or physical activation [2, 5]. Stress is also often uncomfortable because the need to act is seen as a threat and because there is a perceived imbalance between demands and resources. Stress is also common to all high-risk professions but is a personal experience [2, 3, 6]. In short, we perform a situational assessment and feel stressed if we feel threatened or unprepared or under-resourced.

Of note, in its original meaning, stress was not always negative: it simply described activity and arousal [2]. At low levels, stress stimulates attention, focus, and vigilance, and this can aid task completion [2, 3, 5, 9]. Interestingly, when faced with personal disaster, people appear to perform best with a mildly elevated heart rate (typically, 115–145 beats per minute) [2]. However, for every gift that adrenaline gives, it takes one away. For example, higher heart rates are associated with both exhaustion and impaired decision making. In the battle to decide what to prioritize and what to neglect, our senses may become heightened, but stress hormones interfere with complex thinking [2]. Accordingly, soldiers are taught strategies such as "combat breathing techniques" to manage the undesirable physical effects of stress (breath in for four; hold for four; out for four) [2]. It is also why soldiers train so often that the unfamiliar and stressful becomes familiar and automatic. As outlined, under stress, our ability to see (and our judgment) shrinks such that we reduce periphery vision (and peripheral judgment). We can also get tunnel hearing where certain sounds are muted and others amplified [2]. As such, stress is closely associated with fixation errors [5].

A notorious fixation error occurred in 2005 in the UK [15, 16]. During anesthetic induction of an elective case, a mother of two, Ms. Elaine Bromiley, could not be intubated with an endotracheal tube. Multiple consultant anesthetists repeatedly attempted laryngoscopy. Each failed to sound the alarm or to move on to alternate strategies. Similarly, less senior members were concerned but failed to intervene. Tragically the patient (whose husband was a pilot and an expert in crisis management) died with severe anoxic brain injury. Similarly, in the trauma bay, physicians have been known to focus on the abnormal ECG while the patient's oxygen saturation declines unnoticed. In other words, once we appreciate the basics of how we respond to crisis, our behavior makes more sense, and we are more likely to guard against it. Accordingly, we should speak less of medical errors as if they are unique and surprising and more of predictable human errors but in an unforgiving high-stakes medical environment.

The inability to cognitively reevaluate is also known as task myopia or task saturation [2, 5, 17]. Our tendency to fixate can be mitigated by stepping back literally and figuratively. For example, the senior physician standing back from the action often surprises junior colleagues by his/her ability to pick up on peripheral things that they missed ("have you considered this possible diagnosis, doctor?"). As outlined above, lifeguards (but also the police) are taught to scan to the full extent of their peripheral vision to avoid fixation. In the complex environments where even scanning techniques are insufficient, we can reduce stimuli into manageable pieces through task delegation. For example, commercial pilots assign one person to focus solely on flying the plane at all times, while other routine tasks (e.g., navigation or radio communication) are delegated. Within a medical team, we can do similarly (e.g., "I am going to intubate. I won't be able to see the monitor—you manage the blood pressure").

As discussed, our brains function better when familiar with the problem. We feel more in control basically because we are and because we can model and predict [2, 5]. In contrast, cognitive overload and the absence of a working model can lead to feeling out of control and out of rational responses.

Therefore, we are more likely to resort to primitive reflexes such as panic (i.e., the hysterical airline passenger on a turbulent flight) or even paralysis (i.e., the passenger who refuses to leave a burning plane) [2]. Interestingly, paralysis may also be a misguided ancient evolutionary survival technique where the motionless prey looks dead and is therefore avoided by a predator.

It appears that every animal (including humans) has the instinct to shut down under extreme fear (e.g., the deer that freezes in the car headlights; the human that refuses to leave the burning building) [2]. We also tend to exhibit to herd instincts in a crisis. This is probably why we are typically more obedient when disaster strikes [2]. Therefore, flight attendants are instructed to be firm with passengers during an evacuation. In the same way that an animal comes out of its daze after a loud noise (i.e., the slam of a car door), a human can be reoriented with unequivocal orders. In other words, if individuals have temporarily lost their situational awareness, then it is the team's responsibility to bring them back.

Conclusions

Crisis behavior requires an understanding of where our behaviors originated, how they can be mitigated, and why practice (i.e., crisis immunization) is our best defense. We need to expedite the mental model but then deliberately and repeatedly challenge it. Situational awareness means continually scanning the environment in order to minimize premature closure and selection bias. Each team member is responsible for forming and sharing the mental model. In addition, being the team leader means communicating that mental model, maintaining global awareness, and amplifying the team's situational awareness.

Without deliberate strategies, a small crisis can spiral into a runaway crisis. However, a vicious cycle can also be turned into a virtuous cycle. Strategies include (1) metacognition (being aware of our behavioral norms), (2) mandating checks (due to the likelihood of human error), and (3) regular exposure (ideally through realistic simulation). Managing the medical crisis is a fascinating combination of science, art, psychology, and engineering.

Key Points

- Factors that determine outcome in a crisis are more social than technological.
- First level of situational awareness is the perception of stimuli (aka "cues").

(continued)

- Second level requires synthesis with the goal of comprehension.
- Third level involves projection, anticipation, and planning.
- Our attention and response to stress can be improved upon by metacognition (being more aware of our behavioral norms) and through regular "crisis immunization."

Disclosures/Conflicts None.

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Part II

Trauma Team Design

6 Paramedical and Nonmedical Personnel

Sunil Sookram and Arthur Tse

Introduction

Pre-hospital or EMS (emergency medical services) care is one of the fundamental tenants of a trauma system. However, many in-hospital caregivers have little understanding of the roles and responsibilities of this level of health-care practitioner. The names of the various levels of practitioner, scope of practice, skill sets, protocols adhered, access to drugs, and therapeutics differ upon jurisdiction and individual EMS system. This diversity of practitioner titles, practice patterns, and capabilities of the out-of-hospital care provider complicates the understanding and appreciation afforded by the respective in-hospital care providers. Paramedics and non-physician responders or first responders (firefighters and police primarily) play an important part in early out-of-hospital trauma care. This population of caregivers delivers early trauma care, packages and extricates patients from the point of injury, and delivers them onto waiting trauma teams. They carry out early and important resuscitative measures targeted at optimizing the trauma patient's airway, breathing, and circulation. It is important to empathize and appreciate the challenges and resource limitations of typical out of hospital care. Trauma physicians and nurses must have realistic expectations with respect to transportation and ongoing care of the patients that are transported in to trauma centers.

Like many aspects of modern medicine, emergency medical service (EMS) provision began on the battlefield. The first documented ambulance services were organized by Napoleon's chief military physician, Jean Dominique Larrey. "Ambulance volantes" traveled onto the battlefield, treated wounded soldiers, and evacuated them on horse-drawn wagons to aid stations. This strategy resulted in a significant decrease in patients that died from wounds on the battlefield as the wounded were transported to physician care much faster than in the past. In North America, the first ambulances were employed by the Union Army during the American Civil War.

Subsequent civilian branches of ambulance services slowly developed in major cities throughout the United States and offered transport for the sick and wounded to hospitals. In early North American cities, the service was often run by local funeral homes. By the 1900s, medical residents and interns often accompanied ambulances and rendered medical care in addition to the transport provided. At this early stage of development, pre-hospital medical care developed slowly and sporadically in various centers throughout the world. Various systems often coexisted within the same jurisdiction, including hospital-run systems and municipal fire/ambulance systems. By the 1960s, with the first development of closed-chest CPR, the concept of pre-hospital Advanced Life Support (ALS) began to spawn legislation for the provision of physician-driven modern pre-hospital care [1].

North American EMS practitioners training and skill sets have grown significantly over the last three decades. The growth and popularity of the profession has flourished as a result of television and popular culture. The EMS systems across North America are heterogenous but increasing in government (state/provincial) regulation and level of professionalism. In most provinces in Canada, EMS practitioners are regulated professions with their scopes of practice established by provincial governing bodies. This governance is often state regulated in the United States. In Canada, provinces like Alberta, Saskatchewan, and Nova Scotia have established Colleges of Paramedics, and others are migrating toward or close to establishing similar institutions. The Colleges of Paramedics are regulated provincially to ensure quality of care and patient safety. Federally, the Paramedic Association of Canada has established a National Occupational Competency Profile (NOCP) that outlines the expected skills and capabilities of the various levels of EMS practitioner. The NOCP is

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a living document with regular reviews of scopes of practice based upon the growing body of evidence (http://paramedic.ca/wp-content/uploads/2012/12/2011-10-31-Approved-NOCP-English-Master.pdf). While the nomenclature may differ slightly based upon the country, or jurisdiction, the fundamental principles regarding the scope of practice between the various levels of practitioner are fairly consistent within an NOCP. In different countries and regions similar paramedic regulatory processes exist, but the nomenclature may differ. Within each EMS system, individual EMS practitioners follow established EMS Medical Protocols also referred to as Medical Control Guidelines (MCG) which establishes the medical expectations and management pathways for various patient presentations. In the United States each individual EMS system must have a medical oversight plan, which similarly establishes procedures and protocols that govern individual practitioner's practice. The local state governments establish the regulatory framework.

The guidelines or protocols that EMS practitioners utilize are revised regularly by the EMS systems medical oversight, often a physician called the medical director for an EMS system. In most EMS systems there is direct and indirect physician oversight. Direct oversight refers to the real-time communication with practitioners by physicians to give advice and medical orders. Indirect medical oversight involves medical input into an EMS system medical policies, practitioner education, setting practice standards, and expectations.

There are several levels of EMS provider and the nomenclature is different and sometimes confusing to the layperson. There are slight differences between provinces and states for expected scopes of practice depending on the level of certification. While in Canada, the NOCP outlines the national expectations, some provinces have opted to create their own provincial occupational competency profiles that govern each individual practitioner's scope of practice within their own jurisdictions. In the United States, individual states will establish the occupational competency profiles.

Advanced Life Support (ALS) EMS systems have been introduced throughout. This level of care means patients have access to an Advanced Care Paramedic, their skills, and armamentarium. In many parts of Europe, ALS care is delivered by physicians that staff the ambulances. Countries like France and Belgium have evolved these systems likely due the larger numbers of physicians available. In contrast, outside of Quebec, most North American systems have only used paramedical personnel.

There have been clinical trials looking at the utility of ALS care systems and whether they are advantageous over Basic Life Support (BLS) EMS systems. The controversy continues, but the Ontario Prehospital Advanced Life Support trial (OPALS) showed little advantage of ALS over BLS in the setting of major trauma [2]. The priority should be rapid extrication and transport onto waiting trauma teams. The greater the on-scene time, the higher the expected mortality and morbidity in the severely injured [3]. Most urban EMS systems in Canada have an ALS system. However, the greatest need for ALS care would be in the rural environment, where transport time to any center capable of carrying out resuscitation, investigations, and definitive care can be quite a distance away. It is in these rural areas that EMS systems have the most difficulty attracting, retaining, and staffing ALS-capable resources consistently. Table 6.1 outlines some of the expected competencies for the various levels of practitioner based upon the current Alberta Occupational Competency Profile (AOCP). This may be a more liberal scope of practice than some of the more conservative programs in provinces like Quebec. In Quebec, Canada, Advanced Life Support or ALS care has traditionally been delivered only by physicians in the ambulances. There has been evolution of this model over the years. However, ALS care in Quebec is still in its infancy.

Basic Life Support or BLS care is deemed when Primary Care Paramedics (PCP) only provide EMS response. Where limited ALS is available, BLS paramedics may provide first response to a trauma scene with or without ALS backup. EMS systems have evolved novel strategies to utilize ALS care. Some have mixed crew configurations with an ACP and PCP working on an ambulance. Some systems utilize an ACP on a roving vehicle which back up BLS practitioners when needed. EMS systems find solutions to meet the evolving standards of out-of-hospital care with the levels of practitioner available in their system.

The first responder is often the first on scene during trauma. This is often provided by full-time or volunteer firefighters as part of an integrated dispatch process. There are a few models around North America where police have adopted the first responder role. Regardless, within the public safety model, outside community agencies will work closely with EMS to provide care at the scene of a traumatized patient. First responders provide the extra hands, scene control, rescue, and extrication skills required in a busy trauma scene.

There has been expansion of the practitioner levels in some provinces. A higher level practitioner has been developed, and this is known as the Critical Care Paramedic or CCP. This level of practitioner has the skill sets to safely care for and transport critically ill patients with invasive monitoring, inotropic support, blood products, and mechanical ventilation. The CCP is utilized by larger EMS systems that carry out significant numbers of critical care transports over larger distances. Organizations like BC Ambulance Service (BCAS), Shock Trauma Air Rescue Canada (STARS), and ORNGE utilize this level of practitioner as there are larger volumes of patients that need their services reducing the need for physician, respiratory therapy, or nursing accompaniment on these

Table 6.1 Alberta occupational competency profile: paramedic

	EMR	Primary care paramedic	Advanced care paramedic
	– Human physiology – Basic medical equipment operation (monitors, AEDs, tank regulators) – Vehicle operation – Extrication – History taking and physical examination		
Medications/routes	Assist patient with their own p.o.: – ASA – Glucose IM: Epinephrine	p.o./IM/nebulized: Glucagon, Epinephrine, Ventolin, Atrovent, ASA SL: Nitroglycerin IV: D50W, NS	Multiple medications, including crystalloids, colloids, narcotics, paralytics, and pressors. Administered via: p.o. Inhalation, SL, IV, Endotracheal tube, IO, p.r.
Airway/ventilation	– Nasopharyngeal – Oropharyngeal – Bag Valve Mask	– NPA, OPA, BVM – Non-visualized airways (combitube, King LT) – End-tidal CO_2 monitoring	– All EMT airways devices – Endotracheal intubation – Surgical airways – Utilizing mechanical ventilators, CPAP
Cardiac care	– CPR – AED	– CPR, AED – 3 and 4 lead ECG – Basic rhythm and conduction blocks on 12-lead ECG	– Manual defibrillation, cardioversion and pacing – 12 and 15 lead ECG interpretation including BBBs, NSTEMI/STEMI localization – ABG and basic lab collection and interpretation – Monitoring of arterial line, CVP, pulmonary artery catheter, intra-aortic balloon pump, infusion pumps, central lines
Procedural skills	Direct pressure upon wounds	Hemostatic clamps Pelvic binding Intravenous access	– All of EMT – Needle thoracocentesis – Pericardiocentesis – NG, OG, Foley placement – Basic suturing

ASA aspirin, *NS* normal saline, *PO* by mouth, *SL* sublingual, *IO* intraosseous, *IV* intravenous, *PR* rectal administration, *NPA* nasopharyngeal airway, *OPA* oropharyngeal airway, *BVM* bag mask ventilation, *CPR* cardiopulmonary resuscitation, *AED* automated external defibrillator, *BBB* bundle branch blocks, *NSTEMI* non-ST elevation myocardial infarction, *STEMI* ST elevation myocardial infarction, *ABG* arterial blood gas, *CVP* central venous pressure, *NG* nasogastric tube, *OG* orogastric tube

transports. From the scene response perspective, the CCP crews often respond via helicopter, bring greater comfort, and experience with airway management and critical care interventions. The helicopter is then utilized to transport directly to a Level 1 Trauma Center, thereby facilitating trauma bypass of smaller hospitals. The CCP training program is extensive and often includes periods of physician mentorship. This level of practitioner is often employed in critical care transport systems that include rotary wing, fixed wing, and some inter-facility ground transport teams.

The out-of-hospital environment is austere which poses many challenges to initial responders. While principles like "load and go," which is minimizing scene time and rapid transport onto definitive care, are strived for, the reality is the trauma scene is chaotic with multiple competing interests. Limited resources in personnel and equipment can lead to scene departure delays. The identified need for hemostasis or airway/ventilation maintenance should take priority. However, these processes do take time, which is at a premium in the traumatized patient. One of the more time-consuming steps is patient extrication and packaging. Removing an injured patient from a vehicle involved in a collision is inherently time consuming and takes significant personnel and energy. Current rescue dogma is no longer "removing the patient from the vehicle," but rather "removing the vehicle from the patient." This is confounded with an environment of inclement weather, poor lighting, and patient and or bystander distress. Much of the principles pre-hospital practitioners follow in managing the trauma scene and patient is outlined in established curricula in courses like International Trauma Life Support (ITLS) or the American program Pre-hospital Trauma Life Support (PHTLS). Historically, pre-hospital care has evolved into paramedical personnel that perform many life-saving procedures once only employed in hospitals. Procedures like intravenous volume resuscitation, needle decompression, and endotracheal intubation can be utilized in the field and delivered to the traumatized patient at the point of injury. Many cutting-edge EMS systems adopted and trained their personnel in these skills and encouraged their use. As evidence-based evaluation of practice migrated to the pre-hospital world and greater scrutiny was employed, EMS medical directors and practitioners have had to change their standards of practice.

With the evolution and increasing sophistication of EMS systems, medical evidence has weighed in on pre-hospital care management strategies in trauma. The ongoing debate of “load and go” versus “stay and play” is moot. Rather a strategy of “scoop and treat” is preferred. In the United Kingdom and parts of Europe, physicians can be part of the EMS response. However, even in these systems, where advanced therapeutics and procedures are possible due to the physician present, all practitioners will appreciate that patients need to be transported rapidly from the scene onto a trauma center for definitive care as soon as possible. There will be inherent delays in patient extrication and packaging. Skilled and rapid clinical assessment and patient care should be performed en route with minimal scene time as the goal. Procedures to optimize the airway, breathing, and circulation should be accomplished with minimal delay in transport. Recently, some evidence has weighed in on pre-hospital airway management. There is some evidence showing higher mortality with pre-hospital intubation of traumatic head injuries [4]. As a result there has been a push within the medical oversight community to deemphasize airway capture utilizing rapid sequence intubation strategies in the pre-hospital environment [5]. Thus, receiving trauma teams may anticipate receiving traumatized patients directly from the field with only bag valve mask ventilation, the use of supraglottic airway devices, or patients with decreased level of consciousness (GCS <8) with only supplemental oxygen. Early definitive airway management, including endotracheal intubation, by receiving trauma teams will need to be a priority.

EMS practitioners are migrating into some nontraditional roles. With the shortage of physicians in rural areas, pilot programs have been created by various provincial health systems to place paramedics in the Emergency Departments to screen for illness and injuries and collaborate with other midlevel providers (physician assistants, nurse practitioners) and physicians are located remotely to provide some medical care rather than closing the Emergency Department. There are some urban Emergency Departments that utilize paramedics within their Emergency Department staff. The paramedics are used in a nursing role delivering patient care, at triage or extra hands within the department helping with procedures or tasks (Foley catheter insertion, intravenous starts, fracture splinting) [6]. Because of the nature of initial contact with the undifferentiated patient, the Emergency Department is a coveted learning environment for all levels of health-care practitioner. Paramedic students, of all levels, often have emergency medicine rotations they engage in.

Paramedics and other nonphysician personnel play an important part in the “chain of survival” for traumatized patients. It is imperative that trauma teams appreciate the challenges of care out of hospital, include EMS providers in relevant educational opportunities within trauma systems, and consider the out-of-hospital perspective when designing or modifying trauma systems. At patient handover, the paramedic team has a wealth of knowledge that will help trauma teams better understand and predict injury patterns and hemodynamic stability of the trauma patients. Acknowledging and gathering the information directly from the paramedic team while the initial assessment and resuscitation is carried out in the Trauma Room is a worthwhile and a valuable practice. This will allow trauma care providers to interrogate and elucidate answers to the SAMPLE history, nature of injury, and out-of-hospital course of the patient. This will help with early care decisions and allow a more comprehensive admission process for in-hospital care providers.

Key Points

- EMS is an integral part of an effective trauma system.
- There are various levels of EMS providers, each with different skills sets, competencies, and experience.
- EMS providers are highly skilled individuals that are committed to a seamless transition of care from the out-of-hospital to in-hospital environments.

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Transport Medicine

7

Sunil Sookram and Alison Kabaroff

Introduction

Patient transportation and movement remain an important part of getting "the right patient, to the right place, in the right amount of time, using the right transportation modality." This is paramount in trauma care. While trauma systems have evolved, it will be necessary to move traumatized patients either directly to a trauma center from their point of injury or through the utilization of inter-facility transport from another health facility onto a trauma center.

This patient "transition" from the accident scene or outlying hospital onto a trauma center is notoriously a vulnerable time for patients. Critical incidents are not an infrequent occurrence during transport. In-transit critical events have been reported 5.1 % of the time [1]. The goal of transport medicine is to "maintain or improve a patient's medical condition during transport." It is precisely why transport mediums are selected that reduce out-of-hospital time; skilled crews are assembled to care for a patient during transport; and cutting edge technology is applied to look for and manage ongoing patient medical issues. The natural history of the severely injured patient is generally a worsening condition without surgical and/or critical care interventions.

Trauma patients that have their injuries close to a trauma center, or within a designated geographical distance that a trauma system establishes patient safety is not compromised, should be transported directly to the trauma center. "Trauma bypass" protocols should be created within EMS systems to utilize ground transport directly onto a trauma center or integrate aeromedical transport into the transport plan to facilitate rendezvous with aeromedical resource (fixed and rotary wing) to transport directly to a trauma center. The decision on which patients should bypass the smaller non-trauma center is trauma system specific but should be based upon the CDC's 2011 Guidelines for Field Triage of Injured Patients (Fig. 7.1).

Skilled and trained paramedical teams should be able to provide ongoing stabilization and resuscitative measures as a trauma patient is transported onto a waiting trauma team directly from the scene. Established protocols will allow both BLS (basic life support) and ALS (advanced life support) teams to care for this patient population and expedite them onto appropriate care. Minimal on scene time is considered the standard of care. As a result, the direct to trauma center population should have any procedures required done en route to hospital and not on scene. Patient packaging is often rudimentary as it is likely that one EMS caregiver is driving the ambulance and another one remains at the back of an ambulance unsecured trying to manage the trauma priorities—ABCs. Prenotification of the receiving center is paramount to facilitate preparation at the trauma center, and if the patient's condition deteriorates in transit, a plan to consider ongoing physician stabilization at a health facility en route should be considered to allow for advanced procedures beyond the capabilities of the paramedical personnel and early administration of blood products.

The reality of many countries' geography is that direct transport into a level 1 trauma center is sometimes impossible or not best for patient safety. Distances may be too great and inclement weather may impair or delay ground transport. Other mitigating steps may be that hospital facilities are present closer en route, and it is perceived that definitive or higher levels of care can be brought to bear; more aggressive resuscitation can be offered; the need for some technical procedures or skills is required more urgently (endotracheal intubation, tube thoracostomy). In such cases, EMS transports to a non-trauma designated hospital where some initial investigations and resuscitative efforts are carried out by hospital teams.

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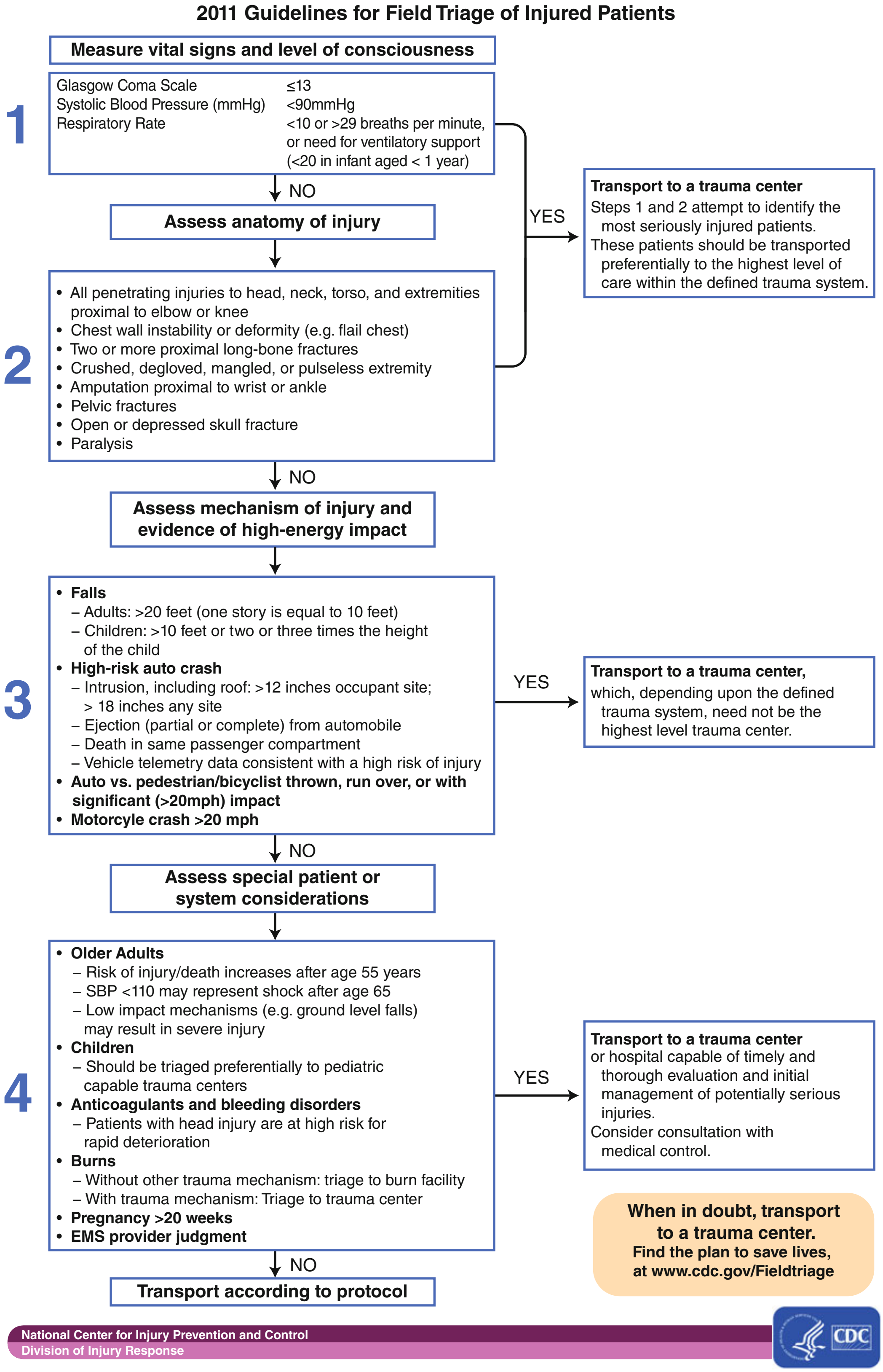

Fig. 7.1 CDC field triage guidelines. Source: Centers for Disease Control and Prevention

Table 7.1 Trauma center designation

Level of care	
1	Central role in the provincial trauma system and majority of tertiary and quaternary major trauma care in the system. Academic leadership, teaching research program
2	Provides care for major trauma. Some trauma training and outreach programs. Similar to level 1 without academic and research programs
3	Provides initial care for major trauma patients and transfers patients in need of complex care to level 1 and 2 centers
4	Major urban hospital with a nearby major trauma center (levels 1–3). Does a large volume of secondary trauma care. Bypass and triage protocols are in place diverting major trauma patients to level 1 and 2 centers
5	Small rural community hospitals or treatment facilities with little to no immediate access to level 1–3 trauma centers. Most trauma patients are stabilized, if possible, and rapidly transferred to higher level of care

Adapted from: Trauma Association of Canada. Trauma System Accreditation Guidelines [Internet]. June 2011 [cited 2014 Aug 27]. Available from: http://www.traumacanada.ca/accreditation_committee/Accreditation_Guidelines_2011.pdf [2]

Trauma systems have evolved a classification system of hospitals and healthcare facilities that categorize the trauma management capabilities. Level 1, the highest, has all resuscitative, surgical, diagnostic imaging (interventional radiology), critical care capabilities. A Level 5 center accounts for the small rural community hospital with no immediate access to level 1, 2 and 3 trauma centers. The expectation would be that patients are stabilized and rapidly transferred onto higher level of care (Table 7.1) [2].

While trauma systems continue to strive toward all peripheral hospitals applying consistent principles to caring for trauma patients, using approaches like that identified in Advanced Trauma Life Support, patients ultimately need to be moved onto centers capable of managing their definitive medical issues. The transfer of care process should be initiated at the earliest opportunity. Most physicians will appreciate very early in the patient encounter that the patient needs a higher level of care and will require inter-facility transport. However, the decision to initiate the transfer of care process is often done after lengthy investigations and time has lapsed. This additional time until definitive surgical care will influence patient temperature, end organ perfusion, and coagulopathy. Early initiation of the transfer of care process will start a cascade of events that will get an appropriate transport team to the sending site concurrently with the ongoing investigations and resuscitative efforts at the sending facility. Early transfer onto definitive care will mitigate increasing morbidity and mortality.

This subsequent inter-facility transport will begin by a transfer of care process from a sending physician onto a receiving trauma team. This conversation may be facilitated by a regional communications hub that coordinates the consultation, facilitates appropriate transfer, and provides advice on patient packaging and ongoing resuscitation needs. There are several examples of these effective communication centers that have affiliated critical care or emergency medicine physicians providing transport medicine and resuscitation advice to sending and receiving physicians. Some of the examples in Canada include CritiCall in Ontario, the STARS Emergency Link Centre throughout the Prairie provinces, ORNGE Communications Centre, and the BC Patient Transfer Network (PTN). In the United States, various hospital systems organize their own centers, for example, the University of Maryland's *OneCall* system.

Inter-facility transport of the trauma patient can be inherently difficult in many countries. The varying geography, great distances, and diverse weather patterns complicate safe and rapid patient transport. The issues and principles that have to be juggled include establishing the fastest pathway on to the relevant trauma center—i.e., ground ambulance, fixed-wing transport or rotary-wing transport; availability of transport modality; capabilities of transport modality; and available personnel depending on the patient's needs. Each of the transport modalities has advantages and disadvantages. Prolonged ground transport is inherently dangerous for EMS crews and the community as a whole when driving "lights and sirens" over a significant distance [3]. Rotary-wing transport allows direct site-to-site service when both have air transportation regulatory body-approved landing sites but has a record, especially in highly populated areas in the United States, of significant accidents resulting in injury. The Federal Aviation Agency (FAA) issued a "black box" warning against helicopter EMS (HEMS) systems in the past and insisted on the widespread implementation of safety systems to mitigate the identified risks. These recommendations are in the process of implementation worldwide. The challenge of fixed-wing transport is the need for multiple patient transfers into and out of the aircraft and subsequent ground transport between airfields. This process does delay out-of-hospital time. However, the range of operations offered by fixed-wing transport facilitates trauma care over large distances.

The EMS ethos has always been that the level of care delivery should not decrease while a patient is transferred from one site onto higher levels of care. The inter-facility transport capabilities should be able to maintain or continue effective resuscitative strategies en route. Ultimately, attempts should be made to minimize out-of-hospital times; as the EMS environment is austere, clinical monitoring and continued delivery of care can be limited due to space and human resources. In the hospital, caregivers must appreciate that during transport, care delivery must be limited. Psychomotor skills are difficult to perform (endotracheal intubation, intravenous initiation, splinting) in a closed space with limited resources. Due to noise and vibration (sirens, helicopter rotor, radios), auscultation and continuous monitoring is also challenging.

The medicolegal risk during the patient transportation process is equally shared between the receiving and sending physician. It is imperative that the consultation process covers the resuscitation expectations, patient preparation for transport, and transport medicine issues. Some trauma systems have access to Transport Medicine Consultants that join the consultative process and provide advice on these issues. If we are to ensure that patient level of care is not to decrease during the vulnerable interhospital transport period, it is important that we all consider these issues.

Patient Considerations

In order to optimize patient management for and during transport, the approach used includes:

1. Adequate patient preparation for transport
2. Patient monitoring and ongoing resuscitation en route
3. Seamless transition onto receiving medical teams and comprehensive handover procedures

Adequate Patient Preparation for Transport

The time during transport is a vulnerable period for patients. While vigilance is a priority by the transport team, the environment is austere, and patient monitoring technologies are hampered by many factors during transport. This is confounded by the natural progression of the underlying pathology sustained during the traumatic event. The injuries that have occurred leading to the need for patient transport to a trauma center are likely going to evolve over the time to get to the trauma center; therefore, time is of the essence.

To minimize the impact of the evolving patient condition, patients are prepared for transport to facilitate the management strategies to deal with potential hazards during transport. It is important that the receiving consultant and the transport medicine consultant address these concerns with the sending center and the transport team. The same approach as ATLS should be applied in assessing and packaging the patient for transport. One needs to anticipate potential problems and prepare to deal with them at the sending hospital.

Airway with C-Spine Control

If there is a potential for the airway to be lost during transport, it should be captured before leaving the sending center. A decreased level of consciousness, patient combativeness, and concern about impending airway loss from hematoma or edema should prompt airway capture by the most experienced airway person at the sending site. A tenuous airway is not optimum in transport; as the intubating conditions are not the best, the success of intubation in the austere environment is less, and the patient positioning for safe intubation in transport is not present. Because of the need for maintaining cervical spine restriction, optimum intubating conditions cannot be achieved in transit.

Breathing

If a potential exists for worsening ventilation during transport leading to hypoxia or poor ventilation, the airway should be captured and mechanical ventilation initiated. Patient conditions like flail chest, large pulmonary contusion, and requirements for large amounts of analgesic medications all can impair patient ventilation over time. Preexisting medical conditions that impact ventilation (chronic obstructive pulmonary disease (COPD), morbid obesity, congestive heart failure (CHF)) that would worsen while in a supine condition (required to maintain spinal motion restriction) should lead to airway capture and mechanical ventilation before leaving the sending site.

If there is a potential pneumothorax or hemothorax due to significant thoracic trauma, it should be managed before sending the patient onto the next destination. Tube thoracostomy is difficult to perform in transit and may be outside the scope of practice of the transport team. Over time, thoracic trauma will likely result in worsening oxygenation and ventilation. From a transport medicine perspective, it is safer to perform procedures like tube thoracostomy in a hospital. This is especially true in the setting of aeromedical transport, where Boyle's law (pressure is inversely proportional to volume) would have pneumothorax expand in the hypobaric environment of altitude (fixed and rotary wing). Depending on the anticipated out-of-hospital time, thoracic trauma can contribute to worsening ventilation and exacerbation of the shock state. Any patient condition that can potentially worsen should prophylactically be intubated and mechanical ventilation initiated. Vigilance for potential issues in transport and dealing with them prior to sending in a transport vehicle are paramount.

Circulation

Similarly, anticipating potential issues from a circulation standpoint and preparing for potential exacerbation are important. Managing circulatory issues in the setting of trauma primarily involves having the patient preparation and resources to manage hemorrhagic shock. Open wounds that potentially will continue to bleed need to have at least temporary hemostasis strategies applied. Occlusive dressings are important to stem the bleeding process. Scalp lacerations are notorious for ongoing significant bleeding hidden under the cervical collar and spinal motion restriction apparatus. Mangled extremities or extremity wounds where hemostasis cannot be achieved should have tourniquet applied. Identified fractures of the pelvis that have suspected ongoing bleeding need to be bound to reduce the bleeding process.

Adequate and extra intravenous access is required, so that if one intravenous site is lost in transport, another adequate site can be used to treat the shock state should it occur. These lines need to be secured well to avoid them being dislodged during the transport process. Intraosseous access can be utilized if there is failure to achieve intravenous access rapidly. There may be a need for blood product administration, and the transport team will need to have blood products accessible if needed. They must have the processes and training to administer blood products if necessary. This falls into different scopes of practice depending on the jurisdiction, and on occasion, hospital staff (physicians or nurses) are required to accompany the patient during transport if there is a requirement for administration of drugs or therapeutics that fall outside the scope of practice of the available transport team. Continuous hemodynamic monitoring is important to examine the adequacy of the resuscitation process. Some Critical Care Transport teams can monitor invasive arterial lines or central venous pressure monitoring. One of the more rudimentary ways of assessing end organ perfusion is by monitoring the urine output. Transport teams will use the Foley output to guide fluid resuscitation. As the younger trauma victim has good hemodynamic compensatory mechanisms and falling urine output may be a late finding, all hemodynamic parameters including serial point-of-care testing are currently utilized by transport teams. All tubes including the chest tube output will be monitored by the transport team. From the receiving trauma team standpoint, reviewing the transport team's fluid documentation is important.

Disability
Intubated and mechanically ventilated patients will receive adequate sedation and analgesia during transport. The uses of pharmaceutical infusions are often utilized to maintain patient comfort. Transport teams will often conduct their own history and physical exam prior to departure to be able to continuously assess and monitor the level of consciousness and Glasgow Coma Scale. Pupillary changes and evolution of focal neurologic deficits will prompt interventions established in protocols or consultation with the transport physician who acts as online medical oversight. In the setting of traumatic head injury, the priority will be prevention of secondary brain injury by managing and preventing within patients:

Hypoxia
Hypotension
Hypercarbia/hypocarbia
Hypoglycemia/hyperglycemia
Hyperthermia

If signs of herniation syndrome develop during transport, the transport team may seek out online medical advice from their medical oversight system. In suspected spinal cord injury, ongoing peripheral motor and sensory exam will be conducted in transit.

Exposure
Patients should have had a secondary survey completed before transport. However, the transport team will always complete a head to toe examination prior to departure to establish a patient baseline status. The development of hypothermia is very much a possibility in most environments. Patients have their clothing removed, receive large amounts of cooler intravenous solution, and are exposed to the elements in transit. Transport teams are limited in the equipment available to maintain euthermia or rewarm patients because of airworthiness in the aeromedical environment or physical space in an ambulance. Steps should be taken to identify potential hypothermia and initiate processes to mitigate it both at the sending facility and during transport.

Patient Monitoring and Ongoing Resuscitation

With the advent of more sophisticated transport teams, higher attention to detail and use of technology with respect to ongoing patient monitoring during inter-facility transport is possible. Hemodynamic monitors can be followed, and serial resuscitative markers can be determined using point-of-care testing.

Transport teams have been trained to be quite vigilant during the inter-facility transport environment. They are caring for critically unwell patients in an austere environment using technology that does not always tolerate the transport environment perfectly. The background noise and vibration of an aircraft or ambulance make following monitoring alarms and waveforms inherently difficult. Using the hemodynamic parameters created by the transport monitors and the serial patient exam, ongoing resuscitative efforts are continued by the team. The transport teams follow established protocols and use transport physician consultation to guide their patient management. Technologies like radios, satellite phones, and cell phones are utilized. Where communications fail and there is no access to medical oversight, which is a distinct possibility in parts of the land, the crew uses their training and experience to guide ongoing care. Most patient transport systems use only the most experienced EMS practitioners for this role.

Seamless Transition onto Receiving Medical Teams and Comprehensive Handover Procedures

Once arrived at the receiving site, patient transfer processes will occur. Patients will be physically handed over to the receiving trauma team stretcher. The wealth of information acquired from the sending site and during transport will be accumulated and handed over to the receiving team. A written patient care record will be produced by the transport team, but it takes time to enter all the required regulatory and patient data that must be downloaded from the hemodynamic monitoring and produce a document. The transport teams are a wealth of information, and it is advised that they are interviewed by the physician team once initial patient care priorities are complete.

Aeromedical Transport

Patients may be sent by ground or air resources. Unless the helicopter or fixed-wing resource is located close to the hospital, the air environment will often require ground transfer to a collection point for embarkation upon the available aircraft. Patients need to be packaged properly for transport. This means securing intravenous access, endotracheal tubes, and any other appendages (chest tube, Foley catheter, etc.). As these appendages may not be compatible or optimally sized to fit in the transport modality, EMS personnel will need to convert some of these appendages to transport worthy ones. Building redundancy into the patient care plan during transport is important. Making sure that all tubes, lines, and appendages are secured firmly is required. Moving patients into and out of vehicles is done carefully and diligently, to minimize any traction or pulling on the appendages to avoid any dislodgement. If a transport checklist is available prior to leaving, it should be used to ensure that elements of patient care are not forgotten in the setting of a chaotic trauma and also to optimize patient safety.

Both rotary- and fixed-wing transport resources are utilized to mobilize trauma patients. Aeromedical crews often have enhanced training and experience in the management of critically ill patients at altitude. There exist specialized equipment, processes, and protocols that have to be followed to ensure flight safety, aeromedical crew well-being, and optimized patient care. Many jurisdictions have elected to certify the aeromedical EMS practitioner level to Critical Care Paramedic (CCP) status. Additionally, the aeromedical environment has unique challenges that must be considered as we move trauma patients from one health facility onto another. Aircraft fly at altitude. Rotary-wing aircraft fly under 5000 ft, but the fixed-wing aircraft can ascend to greater than 10,000 ft. At altitude, the hypobaric environment exists and can complicate patient care.

Extra care must be taken to adequately prepare patients for aeromedical transport. Because the aeromedical environment exposes patients to altitude and the hypobaric environment, there is the potential for the patient condition to deteriorate within this setting. Working knowledge of the gas laws must be applied to mitigate patient care issues in the aeromedical environment.

Boyle's Law ($P \propto 1/V$)

Pressure and volume are inversely proportional. As one ascends, the pressure decreases and gas expands. So if there is any potential collection of air, it will expand at altitude. Trauma care needs to be adjusted accordingly. If there are any pneumothoraces or potential ones, they should be decompressed on the ground with a chest tube. Should the patient condition deteriorate at altitude, it is difficult to appreciate pneumothorax evolution as auscultation is impossible. Access to the affected hemothorax may be difficult depending on the airframe utilized. It is far safer to place chest tubes liberally on the ground prior to embarkment to optimize patient safety. Other collections of air need mitigation as well. Bowel obstructions should be decompressed with an orogastric or nasogastric tube; limb casts placed on the patient should not be circumferential but rather bivalved; maxillofacial injuries may become more painful at altitude due to an inability of the sinuses to vent.

Dalton's Law (Total = Pressure 1 + Pressure 2 + … Pressure n)

The pressure of a mixture of gases is equal to the sum of the pressures of all of the constituent gases alone. Therefore, at altitude, when the total pressure is less, there will be less oxygen available for the patient. Fixed-wing aircraft often fly above 10,000 ft, but the interior cabin pressure is fixed at around 6000–8000 ft. For those who have normal physiology, normal respiration mechanics, and no ventilation/perfusion mismatch processes, we can compensate for the mild hypoxia at altitude. However, if one has compromised oxygenation or ventilation processes, the mild hypoxia can have a profound impact upon one's respiratory system. If there is a potential for worsened respiratory status, hypoxia, or ventilation issues, it is wise to capture the airway and initiate mechanical ventilation on the ground before transferring into the aircraft.

Universal Gas Law ($PV = nRT$)

Pressure and temperature are directly proportional. As one ascends to altitude, the temperature drops. Hypothermia will complicate trauma resuscitation. It worsens the shock state and must be prevented in trauma care. If the environment surrounding the patient is getting colder during transport, steps must be taken by the sending and transport teams to keep the patient warm, monitor for hypothermia, and prevent heat loss. Trauma patients are already at risk of hypothermia as they likely will have their clothes removed, have received significant amounts of cold fluids, and may be exposed to the elements. Caregivers must remain diligent to prevent hypothermia and take active steps to warm patients up during trauma resuscitation and transport. The use of core temperature evaluation using esophageal thermometers, continuous rectal thermometry, and bladder temperature monitoring using specialized Foley catheters are options to consider. Patient rewarming strategies in the air are limited to equipment that is deemed airworthy by governmental regulatory agencies.

The aeromedical environment poses significant challenges to trauma care. While it may be the fastest way of moving the trauma patient through inter-facility transport or directly from trauma scene to trauma centers within the response radius, highly trained and skilled crews are required. These individuals are often selected because of their clinical acumen, critical thinking, and good psychomotor skills. A collaborative approach should be utilized when working with the aeromedical experts to properly package patients and get them to the trauma center.

Conclusions

The goal of the transport team is to "get the right patient to the right place in the right amount of time using the right transport modality." This complex interrelationship is varied around the world based upon geography and resource allocation. Inter-facility transport by transport teams occurs daily as regionalized health systems move patients to where their needs are met. All trauma team members need to recognize the challenges of caring for critically unwell trauma patients during the transport process and facilitate the seamless transition of care by engaging the transport teams and utilizing the information they have acquired over their time with the patient.

Key Points

- Patient transport remains a notoriously vulnerable time for trauma patients.
- Trauma systems should be structures to include a variety of transport modalities to ensure that trauma patients reach an appropriate definitive center of care in the shortest period of time.
- Essential tenants of transport include adequate patient preparation for transport, patient monitoring and ongoing resuscitation en route, and seamless transition onto receiving medical teams with comprehensive handover procedures.
- Careful attention to the gas laws must be applied to mitigate patient care issues in the aeromedical environment.

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Trauma Team Structure and Organization

8

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Introduction

The American College of Surgeons (ACS) and its Committee on Trauma (COT) have developed the Advanced Trauma Life Support (ATLS) program for healthcare professionals [1]. The ATLS program provides physicians who manage trauma patients with a safe, reliable method for immediate management of the severely injured patient. Tasks are performed in sequence, one after the other, in a programmatically defined order of priority. The original design, however, was targeting individuals working in a setting with limited resources, including limited healthcare personnel.

Ideally, however, trauma care should be a team sport [2]. It is well established that care of the severely injured trauma patient is best accomplished by an organized team [3, 4] that may consist of physicians, nurses, and allied health personnel [5]. A team approach can make the resuscitation more effective and efficient, as tasks can be performed in parallel, as opposed to in sequence.

In 1976, the American College of Surgeons Committee on Trauma published the first resource guide for care of the injured patient [6] that described the concept of trauma care in a team setting. The document has evolved significantly, as has the "trauma team." A modern definition of a trauma team is a group of doctors, nurses, and support staff whose primary responsibility is to receive and care for severely injured trauma patients in a comprehensive and multidisciplinary manner. The trauma team is an integral part of any trauma system. Resuscitation by a specific group of healthcare professionals, with clearly defined roles, led by an experienced trauma team leader (TTL), has been demonstrated to improve patient care and outcomes [7–12] and forms the backbone of care in major trauma centers [5, 13].

Teamwork is recognized as an essential component in ensuring the best outcomes in patient safety [14] and is encouraged to achieve optimal performance [15]. Despite the protocol-driven nature of ATLS [1], human factors may affect team structure [16], leadership, communication [17], and effectiveness [18]. As outlined in Part 1 of this text, nontechnical skills, or crisis resource management (CRM) skills, are increasingly recognized as being invaluable components for optimal team function [19], and the deliberate teaching of CRM skills has been shown to improve team performance [20]. Trauma team training programs have been shown to improve team knowledge and performance in a multitude of settings ranging from US civilian trauma centers [21] to developing countries [22–24] and the military [25]. The most recent edition of ATLS clearly recognizes the importance of the trauma team and its function—and the necessity of training to optimize performance— in order to best care for the injured trauma patient [1].

Ideally, the trauma team should be present before arrival of the trauma patient. Otherwise, the emergency department (ED) response to an injured patient typically begins with an assessment by an emergency medicine (EM) physician, who may have several other patients to follow and can accomplish tasks in succession only. Consultation of additional sur-

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gical specialties might only occur if deemed necessary after the assessment, thereby delaying any response. However, trauma patients can present in physiologic extremis and require urgent diagnostic and therapeutic interventions immediately upon arrival in order to reduce mortality and morbidity. The implementation of dedicated trauma teams has been shown to improve patient outcomes [7, 8, 26] and forms the standard of care in North American trauma centers for severely injured patients [5, 13]. Nevertheless, tailoring an institution's trauma team activation (TTA) criteria plays an important role in appropriately selecting which injured patients require a TTA, and which can be more efficiently managed by the EM physician [5]. As even delayed TTA has been associated with prolonged hospital stay [27], the balance between over-and under-triage must be continuously monitored [5, 28]. How a medical facility meets the needs of the trauma patients will vary among countries; however, the ATLS [1] and WHO guidelines [29] form the backbone of the standards of care for any trauma facility.

The goal of early trauma team activation (TTA) is to mobilize the team members and hospital resources before the patient arrives, so that life- and limb-saving interventions can be provided immediately upon arrival. As well, it is also important to share prehospital information with the team in preparation for the patient arrival and allow members of the multidisciplinary team to garner personal protective equipment, including lead shielding.

The size and composition of the trauma team may vary with hospital size and resources, the severity of injury, and the corresponding level of trauma team activation. Airway obstruction is a rare but exceedingly rapid cause of trauma-related death. Severe brain injury and torso exsanguination cause the vast majority of all trauma-related deaths [26]. Extremity injuries are among the leading causes of disability after injury [30, 31]. Therefore, most high-level TTAs within a resource-rich environment include core team members from anesthesia, emergency medicine, general surgery, neurosurgery, orthopedic surgery, respiratory therapy, and nursing. Other team members may include radiology, critical care, obstetrics, urology, plastic surgery, social work, security, laboratory, and more. Smaller hospitals may only be able to mobilize a less resource intensive team, and less severely injured patients may only require partial team activation. In North America, trauma centers are stratified into levels according to the clinical resources they have as well as the degree of academic and administrative responsibilities within their trauma system; a level 1 trauma center is at the pinnacle of this stratification and will have the largest complement of clinical resources and be able to treat all injuries definitively [5, 13].

All team members, including surgical specialists, perform their investigations and interventions in accordance with established principles and guidelines. The TTL is the "captain." The TTL's purpose is to coordinate the activities of all trauma team members and to ensure that each phase of care is performed thoroughly and rapidly, from the resuscitative phase to the imaging or operative/intervention phase and finally to the transfer of care to the ward, operating room, or intensive care unit. Teamwork is important and extends throughout all aspects of care.

Team Members and Roles

As discussed previously, the composition of the trauma team is variable. Table 8.1 lists typical members of the trauma team. Depending on the level of TTA, members may be added or subtracted according to institutional guidelines. There really is no right or wrong formula; the trauma team composition should be based on specialties and personnel available as well as resources.

Trauma Team Leader (TTL)

The trauma team leader is an experienced physician or surgeon that is the "captain" of the trauma team [5]. The training background of the TTL varies by center, but the TTL is often a trauma surgeon or emergency physician. The leader provides expert management of the trauma patient during the resuscitative phase of their care. This includes preparing the team prior to the patient's arrival (prehospital background such as number of individuals involved, mechanism of trauma, severity of trauma and/or injuries), managing the patient in the trauma bay, caring for the patient during transport and during diagnostic imaging, and providing care until

Table 8.1 Trauma team composition in a major trauma center

Specialty area	Typical component members
Trauma team leader	Qualified attending physician or surgeon
Trauma surgery	Attending trauma surgeon
General surgery	Junior and senior resident
Orthopedic surgery	Junior +/− senior resident
Neurosurgery	Resident
Emergency medicine	Attending +/− resident
Anesthesiology	Resident
Radiology	Radiology technician Radiology resident
Laboratory	Laboratory technician
Nursing	Circulating nurses [2] Recording/documenting nurse [1]
Respiratory therapy	Respiratory therapist
Allied healthcare professionals	Social worker/chaplain Trauma coordinator Trauma NP/PA

NP nurse practitioner, *PA* physician assistant a satisfactory handover has occurred to appropriately skilled personnel, who will continue managing ongoing care requirements. The TTL must have the experience and medical expertise to guide the trauma patient through these phases of care as well as exhibit the ability to work within a team framework and be able to assume its leadership [32]. The TTL must have exceptional skills as a communicator, manager, and collaborator to effectively lead the trauma team. A strictly professional demeanor is essential to maintain the team's focus. The TTL generally stands at the foot of the patient's bed, away from direct patient contact, and is thus able to oversee and direct all the activity of the other team members. As highlighted in Chap. 5, this global focus minimizes the likelihood of committing a fixation error (persistent failure to revise a diagnosis or plan in the face of readily available evidence that suggests that a revision is necessary) [33]. The TTL is responsible for directly communicating with the team members, the operating room, the radiology department members, and critical care unit staff. She/he will decide which diagnostic and therapeutic interventions need to be performed and in what order. The TTL is also responsible for ensuring that the major findings, summary of injuries, and treatment plan are documented in the medical record and also communicated to the remainder of the trauma team. In the event that a patient is accompanied by the police or presents with a stab or gunshot wound, the TTL is responsible for interacting with any officer and ensuring compliance with any jurisdictional requirements to notify the police in the setting of such wounds, as well as protecting the safety of trauma team members [34, 35].

Anesthesiology

The anesthesia representation on the trauma team may consist of a resident. Alternatively, this role may be filled by an emergency medicine attending or senior resident. This person should be positioned at the head of the bed and will be delegated with managing most "airway" issues with the respiratory therapist. The physician will perform endotracheal intubation. One exception to the listed responsibilities for anesthesia may be the "difficult airway" that requires cricothyroidotomy. In many trauma centers, the general surgery team member is responsible for performing surgical airways. In conjunction with the general surgery team, the anesthesia delegate may also be asked to help with managing "circulatory issues." Particularly, they may be asked to place central venous catheters, transfuse blood products (along with nursing team members), and place arterial lines. Also, as part of the adjuncts to the primary survey of ATLS, anesthesia team members may be asked to place orogastric or nasogastric tubes.

Emergency Medicine Physician

Depending on the hospital and even country, the emergency medicine physician may be the linchpin of the trauma team. Given that they are almost always the first physician present and have a broad spectrum of skills, they often play the TTL role but can effectively substitute for many other team members. Airway management, fluid resuscitation, performing FAST, and even some emergency surgical procedures such as cricothyroidotomy and thoracotomy fall within the scope of a skilled emergency medicine physician. The role they fill as part of the trauma team is therefore variable and often dependent on local medical culture. Some countries involve critical care physicians to fulfill this role.

Respiratory Therapy

The respiratory therapist works with anesthesiologist to assist in assessment and management of the airway. They are specifically responsible for setting up equipment including airway devices and adjuncts, ventilators, arterial lines, end-tidal CO_2 monitoring, and drawing and running arterial blood gases. This role will be discussed further in Chap. 9.

General Surgery

The general surgery representation on the trauma team typically consists of a junior resident, senior resident, and/or staff surgeon. In many institutions, the TTL may also be a general surgeon. If multiple residents are present, they should be each positioned at the patient's sides. Using the ATLS paradigm, the general surgery team members are usually asked to manage "breathing" and "circulation" issues in the primary survey of trauma patients. The general surgery team is usually responsible for placing chest tubes to relieve hemo-/pneumothoraces. For "circulation," the general surgery team usually participates in the resuscitation of patients in hemorrhagic shock, along with anesthesia and nursing. As part of the resuscitative efforts, the general surgery team is usually responsible for placing central venous catheters (subclavian/femoral). More importantly, the TTL usually delegates the responsibility of localizing and definitively stopping major sources of hemorrhage to the general surgery team; performing the FAST (focused assessment with sonography in trauma) exam is an important part of the general surgery exam for major sources of hemorrhage. When FAST is unavailable or nondiagnostic, diagnostic peritoneal lavage (DPL) may be performed by general surgery in the unstable patient. Major sources of hemorrhage include the thorax, abdomen, retroperitoneum (including the pelvis), extremity, and external sites of bleeding. General surgery, therefore—in collaboration with the TTL—determines whether or not the patient needs to go to the OR for a laparotomy, thoracotomy, or neck exploration, to angiography for embolization, or remain in the trauma bay for a resuscitative thoracotomy. In addition, general surgery is responsible for reviewing any CT imaging of the torso, abdomen, and soft tissues of the limbs (including blood vessels) and neck with radiology. As well, general surgery is responsible for performing the digital rectal exam of the patient during the logroll procedure.

Orthopedic Surgery

The orthopedic surgery representation on the trauma team may consist of a junior resident, but often, a senior resident may be required especially for the placement of advanced skeletal traction. They should be positioned at the patient's pelvis, will be delegated specific roles in the assessment and management of "circulatory issues," and have prime responsibility for "disability" issues in the injured patient. For "circulation," orthopedics usually will be asked to identify and bind unstable pelvic fractures and identify and splint grossly angulated extremity fractures. For "disability and exposure," the orthopedic team will specifically examine all extremities, the pelvis and spine. The orthopedic team will be responsible for performing a detailed secondary survey of the musculoskeletal system and will review all extremity imaging and spine imaging. In the event of an injury to the spine, either orthopedics or neurosurgery is generally responsible for managing this injury.

Neurosurgery

The neurosurgery representation on the trauma team typically consists of a resident. She/he is responsible for the "disability" component of ATLS, including assessment of the spine on logroll when appropriate. They may make recommendations to the TTL regarding the management of any increased intracranial pressure. They are responsible for immediate interpretation of the CT of the head/CT angiogram and discussion with their attending surgeon regarding any operative management or ventricular drainage. Traumatic brain injury is a major cause of death in multiply injured patients, and early neurosurgical evaluation is essential [26].

Circulating Nurses

The role of these nurses includes placing appropriate monitoring on the patient, inserting peripheral intravenous catheters, obtaining blood samples for the laboratory, assistance in patient manipulation including logrolling, and being the non-sterile assistant to a member of the team who is performing an invasive procedure such as chest tube or central line insertion. They are also responsible for administrating any medications or vaccinations. Nursing roles will be further outlined in Chap. 9.

Recording Nurses

The role of the recording/documenting nurse is just that: to document, on an appropriate trauma medical record, the important findings of the trauma team in their assessment of the patient. This includes recording vital signs, assessments, and nature and type of procedures performed. This nurse is typically situated at the foot of the bed, in proximity to the TTL, so as to gain a view of the vital signs monitors and be able to hear the trauma team's assessment as it is relayed to the TTL. She/he often works in conjunction with the TTL to facilitate team communication, especially with services/ resources not directly present in the trauma bay. As mentioned previously, nursing roles will be further discussed in Chap. 9.

Trauma Team Activation

The trauma team is called into action with a trauma team activation (TTA). The TTA may be in response to prehospital information or information obtained when the patient first arrives to the ED. The value of having a trauma team ready and awaiting the arrival of a severely injured patient cannot be understated, as it allows for appropriate preparation of the room and equipment, introduction and organization of the team, and preparation based on the anticipated injuries of the patient from any prehospital information.

A TTA may occur in a tiered fashion or have graded "levels" of response [36]. For example, a patient with prehospital information that suggests a serious likelihood of requiring operative intervention would garner the highest level response. Patients with penetrating torso trauma or multisystem trauma with hypotension are typically included in this category. For these patients, in addition to the standard trauma team, the trauma surgeon, operating theater, blood bank, and intensive care unit may also be notified. For other patients that have evidence of multisystem trauma but are hemodynamically normal, a lesser activation comprising the TTL and the core trauma team members may occur at the discretion of the charge nurse or emergency physician.

Each institution will have its own method for TTA, which may include dedicated pagers, overhead pages, or even "walkie-talkies" for immediate notification. Notification

Table 8.2 American College of Surgeons Committee on Trauma minimum criteria for full trauma team activation [38] (Used with permission from the American College of Surgeons)

• Confirmed blood pressure less than 90 mmHg at any time in adults and age-specific hypotension in children
• Gunshot wounds to the neck, chest, or abdomen or extremities proximal to the elbow/knee
• Glasgow Coma Scale score less than 9 with mechanism attributed to trauma
• Transfer patients from other hospitals receiving blood to maintain vital signs
• Intubated patients transferred from the scene, OR
• Patients who have respiratory compromise or are in need of an emergent airway
– Includes intubated patients who are transferred from another facility with ongoing respiratory compromise (does not include patients intubated at another facility who are now stable from a respiratory standpoint)
• Emergency physician's discretion

may either alert the trauma team member to proceed immediately to the trauma bay or provide an update on an anticipated trauma with an estimated time of arrival. The developing field of prehospital telemedicine and teleradiology may, in the future, facilitate the transmission of important diagnostic information to the awaiting hospital trauma team so that they may better prepare for the patient's specific injuries [37].

The criteria for a graded activation must be clearly defined by the trauma center and continuously evaluated by the performance improvement and patient safety program [5]. Inevitably, over-triage (triage decision that classifies a patient as requiring TTA when, in fact, they do not) and under-triage (triage decision that classifies a patient as not requiring TTA when, in fact, they do) will occur, but a trauma system should establish and monitor acceptable rates for these. Obviously, under-triage carries a greater threat to patient care than over-triage. Suggested rates for TTA are >95 % of patients with an ISS ≥ 16, and in <30 % of patients with an ISS ≤ 9 [28]. The ACS/COT suggested TTA criteria that are listed in Table 8.2 [38].

The Trauma Bay

The trauma bay, or resuscitation area of the emergency department, is where major trauma patients should be received and is the primary location where trauma patients are treated. The ideal trauma bay has the following characteristics: easily accessible to EMS personnel, well lit (with OR quality overhead lights), spacious enough to accommodate the trauma team and necessary equipment, have the ability to perform plain film radiography, be close to a CT scanner, and be in reasonable proximity to the operating rooms and intensive care unit. Many trauma centers have a dedicated area in, or adjacent to, their emergency department with the ability to care for two or more severely injured patients simultaneously. A typical arrangement of a trauma bay is depicted in Fig. 8.1. It is important that all potentially required equipment be located *within* the trauma bay to avoid unnecessary delays. Equipment should also be grouped together by the requirements for performing each procedure. For example, a "chest tube package" may include a sterile cutdown tray containing appropriate instruments, with a suture, scalpel, chest tube, sterile gown, and gloves taped on top of it, already sitting on its own movable table with a chest tube drain and antiseptic solution on the lower shelf. Similar packages should exist for central venous catheters, thoracotomy sets, surgical airways, and arterial catheters. These packages should also be ergonomically placed in the trauma bay, i.e., the chest tube packages should be placed on either side of the patient's stretcher. A complement of airway management devices must be immediately accessible at the head of the bed; many centers have a standardized "difficult airway cart" placed within the trauma bay. An adequate supply of individual lead-lined protective garments must also be available. Ideally, these are donned as well as personal protective equipment (gown, gloves, full-face mask) by all members of the trauma team as they arrive into the trauma bay, so that trauma patient care is not interrupted when X-rays are performed. An in-depth discussion of the trauma bay environment and its design can be found in Chap. 10.

Trauma Team Function

Above all else, the trauma team must function as a *team*. During the resuscitation of a severely injured trauma patient, a large amount of information is rapidly gathered about the patient's injuries and physiologic condition, and management decisions are similarly rapidly made based on this information, often in a near-simultaneous fashion. The presence of a team allows multiple actions to be accomplished at once compared with a serial or vertical approach required when only one physician is available to treat such a patient. This departure from primary care emergency care provision in a small hospital is important to note.

To function properly as a team, the team needs clear leadership. All information must be passed to the TTL and all decisions must be made by the TTL; otherwise, the team function becomes chaotic. For example, if only one nurse is available and both the anesthesia resident and the orthopedic

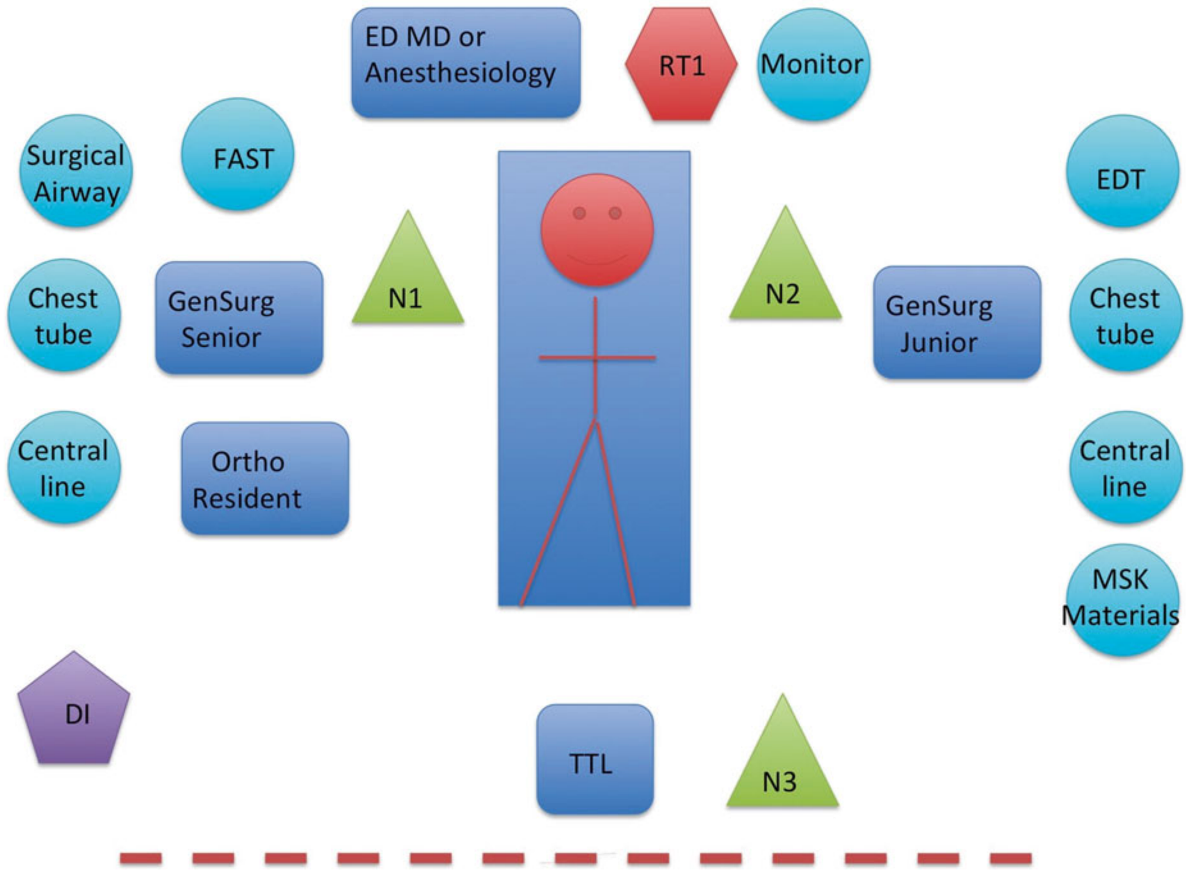

Fig. 8.1 Trauma team positioning in the trauma bay. *DI* diagnostic imaging technician, *TTL* trauma team leader, *N1* and *N2* circulating nurses, *N3* recording nurse, *RT* respiratory therapist, *EDT* emergency department thoracotomy tray, *MSK* musculoskeletal, FAST point of care ultrasound machine

residents are demanding nursing assistance for procedures (arterial catheters versus splints), the requests should go through the TTL, and the TTL must prioritize the order of work and decisively delegate the nurse to one or the other resident's aid.

Table 8.3 lists typical actions taken in the care of a trauma patient who receives a TTA, as well as the possible interventions that may take place. When deconstructed into individual tasks, one can see how arduous it would be to accomplish these all by a lone physician! However, when performed in parallel, with appropriate sharing of diagnostic and clinical information with the other team members and in particular the TTL, patients should spend <60 min in the trauma bay and even faster in the setting of bleeding requiring operative or angiographic intervention or a head injury requiring an urgent CT of the brain. Ideal destinations after leaving the trauma bay are the OR, the angiography suite, the ICU, or the trauma ward. However, if their condition allows, many patients may be required to return to the ED while awaiting bed availability.

Conclusions

The optimal care of the severely injured trauma patient is predicated on the seamless function of a multidisciplinary trauma team under the effective leadership of an expert trauma clinician. Team and venue preparation are key components for success, and attention to the appropriate training—including education, simulation, and quality improvement processes—will allow a trauma team to excel in its care for these patients.

Table 8.3 Typical patient care action points during trauma resuscitation

Standard actions	Possible actions
Arrival in trauma bay	
Receive handover from EMS	
Maintenance of spinal precautions	
Removal of clothing/exposure	
Placement of monitors	
Check patient's temperature	
Achieve adequate intravenous access	Placement of IV, CVL, or IO
Draw trauma bloodwork and send to the lab	
Assess airway	Secure airway
Assess breathing	Administration of oxygen, insertion of chest tubes
Assess circulation	Resuscitate with crystalloid and blood products Identify and control sites of massive bleeding
Chest radiography	Chest tube and/or thoracotomy
Perform FAST	Laparotomy
Check pelvis for stability	Pelvic binding
Check long bones for stability/deformity/bleeding	Splinting, washout of open wounds Tourniquet application
Assess for external bleeding	Apply pressure/close wounds/tourniquet
Assess disability	
Logroll patient, examine spine, perform DRE	
Obtain chest and pelvic X-ray	
Administer tetanus prophylaxis as appropriate	
Administer antibiotics as appropriate	
Complete secondary survey	Obtain MSK X-rays as needed; suture/repair wounds as needed; place Foley catheter and NG tube
Arrange for any necessary CT scans/radiology	
Complete trauma medical record	
Handover care to appropriate service	

EMS emergency medical services, *CVL* central venous line, *IO* intraosseous, *FAST* focused assessment with sonography in trauma, *DRE* digital rectal exam, *MSK* musculoskeletal, *NG* nasogastric

Key Points

- Treatment of a severely injured trauma patient is a complex process.
- Optimal resuscitation is best accomplished with a multidisciplinary team.
- Team function is dependent on technical as well as nontechnical skills.
- To optimize team function, it must be practiced.

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Interprofessional Trauma Team Roles

9

Elaine Sigalet and Mirette Dubé

Introduction

As highlighted in previous chapters, optimizing the management and outcomes of trauma patients requires effective and efficient interprofessional team performance [1, 2]. In addition to having strong inclusive leadership, it is important to identify both the task work and interdependence of task work associated with medicine, nursing, and respiratory therapy team members [3]. Increasingly, healthcare professionals (especially those in educator roles) are recognizing the value of interprofessional (IP) training. IP education was developed to emphasize the relationship between the knowledge, skills, and attitudes required for individual task work and effective interaction between team members to optimize patient outcomes [4]. Educational modalities such as simulation allow us to learn with, from, and about each other's roles and also about the skills and knowledge needed to work effectively and efficiently together to optimize patient care. Although this seems straightforward, the task of engaging teamwork concepts, inclusive of leadership roles and responsibilities, communication, situation awareness, and resource utilization in an interprofessional context is complex [5].

Regardless of profession or discipline, each team member brings knowledge, skills, and attitudes, which are influenced by the immediate context. It can be helpful to view these factors using the paradigm that Ilerus calls the "tension triangle" [6, 7] (Fig. 9.1). The tension triangle represents how each team member experiences the situation, and that in turn influences learning. As human beings, we structure and store knowledge from curricula and our experiences in schemas to facilitate the retrieval of knowledge as needed [8]. Emotions and stress can impede an individual's ability to retrieve knowledge in the moment, and this can potentially negatively impact team performance. In the care of trauma patients, the emotional response of caregivers is influenced by the patient's emergent needs and the interaction of team members. In order to optimize team performance, one must create a context conducive to knowledge retrieval, behaviors that support team members in their role so that their emotion does not impede their ability to optimize task work and interact effectively with other team members. This can be critical to the success of the team.

The complexity of a team's mind-set is further exacerbated when the membership of the trauma team changes and/or the patient condition changes [9]. The concepts of crew/crisis resource management (CRM) were developed to guide the composition of teams and to define team roles and necessary task work; this provides a framework that supports emotional stability so that information and resources remain accessible despite changes within the team which may occur [5]. Support for these concepts and IP trauma team training is validated by the many reports on the relationship between team member interaction and adverse events; breakdowns in communication process have been identified as contributory to most adverse events in patient care [10–12]. To add clarity to IP trauma team training, it is important to (a) identify team membership, (b) establish specific roles, and (c) recognize the interdependence of team roles in a context of CRM concepts.

Leadership

Leadership, roles, and responsibilities, as articulated in CRM, provide a framework for trauma team membership. As discussed in the previous chapter, in many emergency department trauma centers, the most basic of trauma teams consist of a leader, three nursing team roles, and often a respiratory therapist. Although this configuration of roles may be

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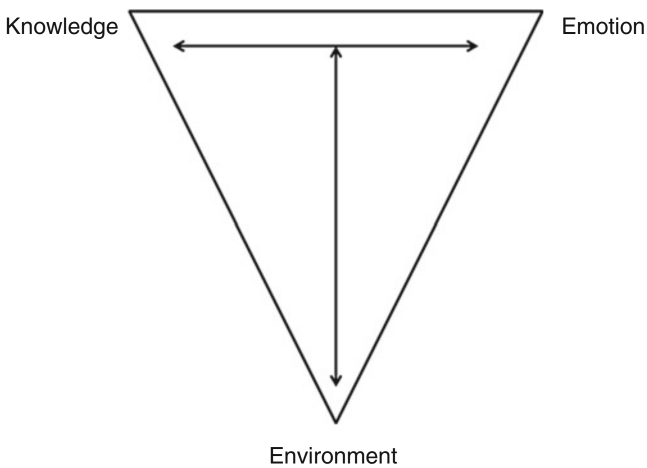

Fig. 9.1 The tension triangle

somewhat different in different states and countries, consistent membership includes a leader and nursing or other healthcare professionals dedicated to the airway, procedures, and medications. Leadership takes many different approaches. Many trauma team leaders were taught to use an authoritarian approach, and this culture pervades even today. However as education changes, so does the culture within health care; trauma team leaders today are more aware of the need for creating an inclusive context that not only supports all team members, but enhances engagement by providing autonomy within the group [13]. There is a great deal of evidence which supports this leadership style dating to the early 1940s. Kurt Lewin, a German/American psychologist, found that school children did the highest quality work under a democratic leader, but produced the greatest volume of work under an authoritarian leader [14]. Children were least productive under "laissez-faire" leadership. Please see Chap. 3 for a further discussion of leadership styles.

After studying levels of psychological safety, i.e., how group members think they are viewed by others on the team in health professionals in 26 NICUs in the United States, Nembhard and Edmondson reported a relationship between professional designation and level of psychological safety with physicians being the most safe, followed by nurses and then respiratory therapists [15]. They coined the term "leader inclusiveness" to illustrate important behaviors in creating psychological safety among team members. Verbalizing acceptability of team member questions and concerns and actively seeking team member thoughts on treatment decision was viewed as important in establishing leader inclusiveness; in this environment of safety, team members are more willing to speak up when they have information or a concern to share, thereby limiting the possibility of adverse events from occurring. There is preliminary evidence from simulation training showing a relationship between the effectiveness of established trauma teams and the willingness of team members to speak up [16]. Trauma team members thrive in an environment where the leader verbalizes value for team member input; this is especially true in challenging circumstances.

Nursing Roles

Nursing roles in the trauma team are typically designated by task work: documentation, medication administration, and procedures. Documenters usually position themselves at the foot of the bed where they can retain a visual of the entire context of all team members performing task work and the patient. In most trauma teams the most experienced nurse takes on this role due to its complexity explaining why in some centres this role is referred to as the "Trauma Nurse Leader". This nurse is responsible for obtaining a history and then recording in real time the primary and secondary survey assessment, including changes in patient condition, and documenting team member interventions. Many trauma team leaders position themselves right next to the documenter to maintain situational awareness. The interdependence between the leadership and documenter allows for clarification on patient condition, completed or not completed interventions, and this supports effective anticipation and planning.

It is very important for the documenter to record the findings verbalized by the leader of the primary and secondary assessment in real time. Unfortunately, due to the intricacy and sometimes the amount of detail required by the trauma record, the documenter focuses on working through the record from initial arrival details, and this can impede the ability to capture the primary and secondary survey in real time. These initial descriptive data points must be recorded quickly or updated after capturing essential assessment data. Repetition of work is distracting and may disrupt the team's attention as it moves through the expected sequence of primary survey, interventions, and then secondary survey. Additionally, the documenter assumes responsibility for ensuring closed loop communication. The leader orders a team member to complete a task, and the team members acknowledge the order, complete the task, and in an audible voice communicate the completion of the task to both the documenter and leader. When these loops are not closed, it is the responsibility of the documenter to ascertain whether or not the task was completed and inform the leader.

The documenter is also the timekeeper and as a result is responsible for informing the leader and team when time lapse is important in determining further intervention. An example of this is the administration of epinephrine in a resuscitation context. The leader has asked the medication nurse to administer 1 mg of 1:10,000 epinephrine intravenous push every 3 min until the return of spontaneous circulation. The documenter having recorded the time of the last dose would communicate the time lapse and need to repeat the dose after 3 min, if the context still requires that intervention. When patients have emergent needs, team members act in their role simultaneously to improve efficiency and effectiveness of management. The leader often gives the team many different orders, but this type of approach can cause confusion and increased risk for communication breakdown and adverse events to the patient. To alleviate the risk, leaders are encouraged by the documenter to write down the necessary interventions prioritizing behaviors dictated by patient condition. The documenter can then assume responsibility for sharing this priority list of interventions so that team members do not get overloaded in the demands of their role. Experienced team members can help less experienced team members stay on track if they deviate from the care sequence. So too can the team's collective experience be tapped to help solve unexpected changes in the patient's condition. Having the most experienced nurse act as a documenter maximizes the stability of the nursing team's emotional tension. Team members draw on the documenter or leader for clarification of orders, available resources, and reaffirmation of behaviors to optimize task work. The documenter, having had more experience in emergent situations, is usually very aware of the cognitive aids available, the resources, and how to access resources in a timely fashion.

The procedure nurse usually assumes a position on the opposite side of the bed to the medication nurse to support simultaneous task work without crowding other team members. The procedure nurse is responsible for putting the patient on the cardiac monitor, initial assessment of vital signs inclusive of temperature and glucose, and any other procedures ordered by the leader. Other procedures frequently include further intravenous (IV) access (two large-bore IVs), crystalloid or blood administration, procurement of trauma labs, and the insertion of a Foley catheter and nasal or oral gastric tube post-intubation. If the situation requires the use of the rapid pressure infuser, which delivers about 300 ml/min of resuscitation fluids, a fourth nurse may be needed to support the team. The pressure infuser requires the full attention of one nurse to operate and monitor rapid fluid administration safely. The procedure nurse is expected to acknowledge all orders, clarify if necessary, and verbalize clearly the completion of a task as required by all team members.

The third nursing role typically assumed on a trauma team is a medication nurse. Trauma patients are frequently in need of medication support for their emergent needs. Examples include rapid sequence intubation medications, inotrope or vasopressors for hemodynamic support (in special trauma circumstances), volume expanders, antibiotics, tetanus, and resuscitation drugs. This can be a very busy role and is often supported by the procedure nurse if procedure task work is completed or deemed not a priority when compared to medications. The documenter can also support this role as far as checking medication dosages, blood products, and accessing resources. Again it is critical to situation awareness that the medication nurse closes the loop on all medications, including type, dosage, and route, in a manner audible by the entire team. Although all roles require focus, which can impede maintenance of situation awareness, this is more profound in this particular role. This role takes the nurse away from the immediate bedside to the medication cart and pharmacy resources. With their back to the patient, it is critical that the nurse in this role reaffirms the need for the medication before delivering as the context may have changed and the nurse may not be aware of the changes. This adds one extra step to closing the loop. After acknowledging the order and preparing the medication, the nurse should announce the intention to deliver the medication and await affirmation that it is still needed to deliver it, again verbalizing completion of the order once the medication is delivered (Fig. 9.2).

Respiratory Therapist Roles

The specific role and presence of the respiratory therapist (RT) varies internationally and even from center to center in some countries. Although there is a paucity of research examining the RT role in trauma management, Steinmen and colleagues report a benefit for early trauma care after a short in situ simulation-based trauma curriculum [1]. In addition, there are several studies that suggest a benefit for using respiratory therapy-driven protocols to improve outcomes [17–19]. This section will describe the roles and responsibilities of a respiratory therapist on a trauma team. It is acknowledged that internationally there is variation in who assumes this role; responsibilities described may be carried out by another experienced team member dedicated to airway and breathing. An emergency physician, anesthesiologist, or critical care physician in centers in Europe or the United States may often assume this role.

In Canada, respiratory therapists (RT) are integral members of the emergency department trauma team. Membership on the trauma team usually includes one RT and often two. Task work within the trauma team focuses on anticipation and planning for the admission, dynamic evaluation of respiratory status and pulmonary mechanics, emergent interventions, arterial blood gas procurement, and assessment. The coordination of specific task work is reliant on effective task interdependence between both nursing and medical team members. Furthermore it is important to recognize that although these team members are assigned to the emergency department, they may be required to support other hospital areas as dictated by the demand for respiratory-focused task work. Within the emergency department, they may be required to manage multiple trauma patients requiring

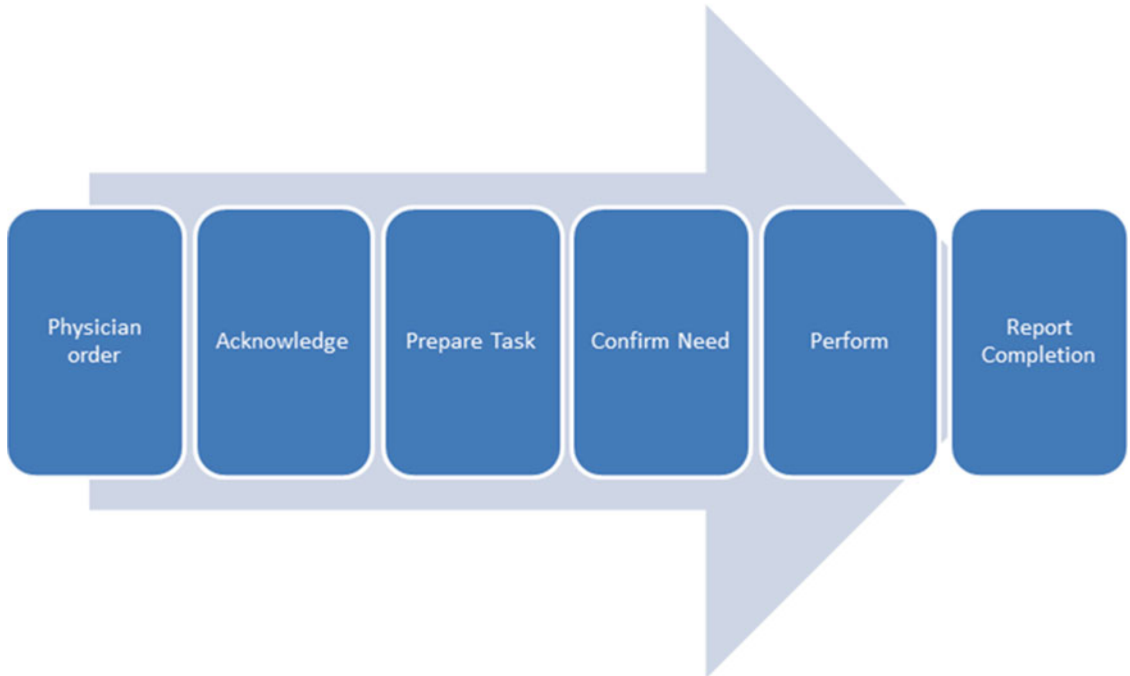

Fig. 9.2 Effective communication pathway

physical relocation from one trauma team to the next. Additionally, they are often responsible for medical patients in the emergency department with respiratory issues, including ventilated patients. This necessitates special attention to maintaining ongoing situational awareness. It is the responsibility of each RT to regain situational awareness when they are required to relocate between trauma teams.

Respiratory therapists are experts at anticipating and planning for emergency situations and as such are invaluable members of the trauma team. Frequently, the RT is the first one at the bedside of a patient with impending respiratory failure requiring emergent intervention. They must relay urgency when calling for help, assess possible risks, and prepare and often initiate lifesaving interventions independently. Although RTs are experts in preparing and engaging various technical machines and equipment (noninvasive machines, ventilators, arterial lines, capnography, difficult airway adjuncts, and level 1 infusers at some sites), their real strength lies in their ability to effectively assess the patient's clinical respiratory status and apply and evaluate these therapies dynamically while working within a team setting. This role is critical to trauma team successes in optimizing patient outcomes.

During trauma patient admissions, the primary RT stands near the head of the bed where they are able to assist the physician in completing the initial primary respiratory assessment. Working closely with trauma team physicians, they are responsible for supporting the rapid assessment of the patient's airway and breathing and identifying and communicating any emergent patient care needs such as airway obstruction (for example a blocked endotracheal tube), the need for airway medications, intubation, and ventilation. It is important that the information gathered on assessment is communicated to all other team members especially the trauma team leader and documenter. In addition it is important to ensure communication loops are closed; the information is heard, and a plan of action is determined and engaged. With intubation, The RT supports the role of the person performing the intubation (RTs perform intubations in some centers) and is responsible for confirmation of the endotracheal tube placement (ETT) and maintenance of airway patency. As such the RT is often the first to discover a dislodged ETT, or other airway emergency, alerting other team members to coordinate rapid airway management to prevent patient deterioration.

In the RT role it is important to verbalize concerns in real time. Concise but clear statements such as "I need the leader's attention right now…, or I am very concerned…." are important to alerting other team members to the change in patient condition. From this perspective the RT should clarify intubation plans with attention to plan B and possible plan C in times when plan A is not successful. Sharing and verbalizing these mental models are critical to bringing the team goals together and being prepared for emergency situations during intubation.

When a trauma team has the luxury of having two RTs, the primary RT supports active airway management, while the second RT observes the patient monitor alerting team members to changes or abnormalities with the patient's physiological status during the intubation. In some centers, the primary RT is responsible for intubation, while the second RT supports active airway management. The important distinction between roles is that the RT in the secondary role is responsible for maintaining situation awareness for team members during the intubation procedure. Timing the intubation and recording number of attempts and patient vitals are critical information. The team member who is intubating the patient needs to know when they need to reoxygenate the patient before further attempts during difficult intubations. Fixation errors (over focus on one task to the detriment of patient condition) can and do occur with tasks such as intubation. In recognizing this, many centers have created policies to enable any and all team members to call for expert or additional help should a fixation error occur, as the patient is at risk.

During times when the patient requires mechanical ventilation, the RT is responsible for initiating, maintaining, interpreting pulmonary mechanics and ventilator waveforms, evaluating the need for advanced modes of ventilation, and sometimes even weaning the patient from the ventilator while still in the emergency department. The interpretation of the pulmonary mechanics is vital to ensuring appropriate ventilation parameters are applied. For example, a high plateau pressure (Pplat) measurement may be interpreted differently based on the clinical findings and history. The RT may need to lower target tidal volume settings to reduce the chance of worsening volutrauma in a patient with high Pplat, compared to a patient they believe has normal lungs and a falsely high Pplat due to transmitted pressures from the abdomen or chest wall. The RT procures and analyzes arterial blood gasses to guide their ventilation parameters and strategies and also brings any physiological abnormalities to the attention of the TTL. In addition, the RT is often responsible for pharmacological assessment and administration of airway medications such as bronchodilators.

Interdependence of Task Work

Having an integrated approach to care and skill sets supports higher functioning and efficient teams and practitioners performing to their fullest scope and abilities. For example, in some centers, both RT and RNs are trained in performing ABGs and IV lines. Should one person be occupied with another task, other members can help.

In trauma management much of the task work is completed simultaneously; on initial patient assessment, the team must work together to transfer the patient from the incoming transport stretcher while maintaining spinal precautions. The nursing attendant assigned to the trauma team cuts the patient's clothes off to expose the patient for primary and secondary assessment while avoiding hypothermia. The primary assessment is conducted, often by a separate physician assisting the leader, while respiratory therapists and nurses are performing concomitant tasks. Respiratory therapists are responsible for having airway equipment ready and transfer oxygen devices to the oxygen delivery system in the ED, making the necessary interventions to optimize airway and breathing. While the patient is being exposed and the primary survey is being conducted, the procedure nurses place the patient on the cardiac monitor with assistance from the respiratory therapist and then place two large-bore intravenous, if not already done en route. Blood for Hgb and crossmatch is taken directly from the IV site or femoral cannulation to access a large vein or artery for blood sampling inclusive of a venous or arterial blood gas. Rapid infusion of fluids is initiated or sustained, with consideration given to the need for the massive transfusion protocol. The medication nurse anticipating the need for a more definitive airway if not established in the field will be preparing the rapid sequence intubation drugs as per physician order.

Anytime there is a change in the patient condition, the documenter or other team members should encourage the leader to provide a situation summary of anticipated diagnosis, interventions completed, and anticipated interventions so that there is collective communication and a shared mental model can be established.

It is the responsibility of each team member to regain situational awareness if they lose it because they had to focus on a task or had to physically leave the trauma. This is important, as changes may have occurred in the patient's condition and also the plan of action. It is also the responsibility of each team member to cross-monitor each other while being attentive to behaviors that may indicate a team member is overwhelmed in their role. An example of this is the situation which evolves if the medication nurse is not able to access a medication, which then delays administration and any subsequent interventions. This should be a flag for other team members to assess the situation and either provide support or ask the charge nurse for more support for that team member role. It is very common for the performance of seemingly routine tasks to be impaired if a team member is unsure of themselves, they are feeling overwhelmed, or the patient's condition is critical. This then impacts on the performance of the entire team. It becomes critical to the ongoing sustainability of the team that these episodes of impaired performance are recognized and dealt with in a constructive and supportive fashion, including the use of debriefing sessions led by experienced personnel. Debriefing should focus on the provision of information to achieve best practice. In many situations it is important to expose the thoughts that drove the action to change behavior. Simulation is an effective learning modality for examining patterns of medical management and the thoughts that drive the management.

Deliberate practice with guided debriefing helps build reflective practitioners who become aware of their individual strengths and their contribution to the team, the strengths of other team members, and the inherent challenges of working in an interprofessional context with trauma patients [20]. Debriefing will be discussed further in Chap. 36.

Conclusions

Trauma team members are human and as such are fallible. Healthcare professionals need to be educated about crisis resource management, the strategies that support effective team performance in emotionally provoking contexts, to optimize both task work and task interdependence to achieve optimal patient outcomes. There is no "I" in team, only a "we," and the team membership must have opportunities to practice in risk-free environments to minimize the risks inherent in trauma management. Simulation is one such initiative and is important because it provides opportunities to practice medical management and effective and efficient teamwork.

Key Points

- Effective teamwork requires inclusive leadership, clearly identified roles, and effective task interdependence between all team members.
- Optimizing team performance becomes reliant on creating a context conducive to knowledge retrieval, behaviors that support team members in their role so that their emotion does not impede their ability to optimize task work and effective team interactions.
- Nursing roles consist of a documenter, medication, and procedure nurse.
- The role of the respiratory therapist includes dynamic evaluation and interventions to support cardiopulmonary status, interpretation of pulmonary mechanics, ABG procurement and assessment, and multiple interdependent tasks to support team functioning.
- Simulation with guided debriefing provides an environment of safety for deliberate interprofessional team practice and the creation/development of reflective practitioners.

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10 The Trauma Bay Environment

Rondi Gelbard and Kenji Inaba

Introduction

The purpose of the trauma resuscitation area is to receive and triage patients that present to the trauma center with injuries of varying severity. The area is used to initiate resuscitation and facilitate the correct disposition of these patients. The trauma resuscitation area should be designed to accommodate high patient turnover and allow a single team to concurrently manage multiple patients. Its design must take into consideration such factors as accessibility, imaging needs, and procedural capability as well as employee and patient safety. This chapter will discuss the physical design of the ideal trauma resuscitation area and trauma bay and the necessary equipment for successful trauma resuscitation. The chapter will also review the importance of direct patient triage from EMS to OR, as well as the benefits of a hybrid trauma/OR suite for the optimal care of the critically injured patient.

General Design of a Trauma Resuscitation Area

Trauma accounts for over 42 million emergency department visits and two million hospital admissions annually across the USA [1]. It is essential that all trauma centers have an efficient system in place in order to adequately receive and manage critically injured patients [2, 3]. In order to accomplish this, trauma centers should have a designated trauma resuscitation area, often housed within or in close proximity to the emergency department (ED). The design of the trauma resuscitation area should take into consideration the hospital's annual and average daily census and should be of sufficient size to accommodate all admissions and interhospital transfers requiring a higher level of care. In many centers, especially those with lower trauma volumes, these rooms are utilized for the resuscitation of all patients, including trauma, non-trauma, surgical and medical, and this must also be taken into consideration. The overall number of individual trauma bays within the resuscitation area will also be influenced by factors such as inpatient bed accessibility and available staffing and should be capable of temporary expansion as part of the hospital's surge capacity plan in case of a disaster.

The Los Angeles County + University of Southern California (LAC + USC) Medical Center is among the busiest level I trauma centers in the USA. Located east of downtown Los Angeles, LAC + USC is a 650–bed hospital that admits over 6,000 trauma patients annually. At LAC + USC, the multi-use resuscitation area is situated within the emergency department and consists of individual rooms each capable of physiologic monitoring and a wide range of invasive procedures including thoracotomies and laparotomies. Other functional areas include a decontamination area, the triage/waiting area, and staff workstations. In addition, a pharmacy, clean and dirty utility rooms, and an adjoining radiology suite are all considered part of the resuscitation area. Each of these components and their spatial arrangement within the Resuscitation area are discussed separately within this chapter.

Access to the Resuscitation Area

The resuscitation area should be located on the ground floor for easy access. The layout of the resuscitation area should allow easy access for ground EMS crews and direct access from the helicopter-landing pad for efficient patient inflow.

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An elevator for direct transportation to and from a helicopter pad is critical for patients arriving via rotary wing transport. For patient outflow, there should be access to the radiology suite, operating room, and the intensive care unit. The routes should minimize distance and travel through non-patient care areas where there is public access protecting patient privacy and promoting public safety. All elevators in the pathway should be large enough to accommodate the team, patient, and ventilator and be card-access-controlled to minimize any delay. The access area must be well lit, and protected parking areas for consultants as well as EMS and law enforcement should be available. Appropriate physical barriers should designate "drop-off" zones for ambulances and other transport vehicles. The entire access area should be secured and large enough to be used as an external decontamination and triage area in case of a disaster.

Immediate access to CT scanning improves efficiency, and a system for the electronic display of images (i.e., picture archiving communications system or PACS) should be accessible from the trauma bays and the administrative areas [4]. The CT scanner should be located adjacent to or within the resuscitation area. A radiology technician must be notified of the patient's imminent arrival and be readily available during the initial evaluation and management of the patient. Rapid access to the intensive care unit and a designated trauma operating room is important for minimizing transfer times of critically ill patients.

Entry to the pharmacy/medication room should be clearly marked and secure. The area should be accessible to all clinical areas and have sufficient space to accommodate a pharmacy preparation area. Warmed fluids should be housed centrally. For higher-volume centers, a satellite blood refrigerator containing O^- or O^+ blood and thawed group AB or low titer group A plasma should be considered. This refrigerator should be located in close proximity to the resuscitation area. In an emergent situation, when the patient's blood type is not known or compatibility testing has not been completed, these emergency release products can be used.

There should be a room for the storage of equipment and disposable medical supplies that are not currently being used. There should also be a clean utility room of sufficient size for the storage of clean and sterile supplies, and this should have adequate workspace for the preparation of procedure trays and equipment. Access to a dirty utility or disposal room should be available from all clinical areas. The physical design of the resuscitation area should allow for rapid access to additional equipment if needed. There must be an emergency power supply for the entire resuscitation area, and a backup system for lighting should be immediately available in the event of a total power failure.

Patient Flow and Disposition

All patient flow upon entry should be directed toward the reception/triage area from which the ambulance entrance should be clearly visible [5]. From here, critically ill patients can then be directed to the resuscitation area. At LAC + USC, once the initial assessment and all necessary imaging is completed, the patient is transported via elevator to one of several different locations depending on their injury: the patient ward, ICU, observation unit, or the operating room. The initial resuscitation should be performed as rapidly as possible. Once the primary survey has been completed and all immediately life-threatening injuries have been addressed, patients requiring surgery should be transferred immediately to the operating room or to definitive care without further delay.

It is important to have a designated transport protocol in place for moving the patient rapidly and safely to these areas [2]. The protocol must ensure that the benefits of the transport outweigh the potential risks and that the same standards of care employed in the trauma bay are also in place during transport. Prior to intrahospital transport, all life-threatening injuries must be addressed, and the patient must be deemed stable enough to withstand transport. A checklist for ensuring that all safety and monitoring issues have been addressed should be considered. There must be an adequate oxygen supply for the duration of the transport as well as a self-inflating bag with PEEP valve, facemask, and oral airway. It is essential that the patient be connected to a portable monitor at all times, with pulse oximetry, blood pressure, and electrocardiography capabilities. Transport equipment should also include basic intubation equipment, resuscitation medications, and IV fluids. A fully equipped trauma team, including a physician, trauma nurse, and respiratory therapist, must accompany the patient to their next destination and be prepared to administer further resuscitation or transport the patient back to the trauma bay or to the OR immediately if necessary.

Surge Capacity

The physical plan of the trauma resuscitation area should allow for temporary expansion in the setting of mass casualty events [2]. In the setting of a major disaster, other patient assessment areas within the emergency department should have the capacity to be converted into functional trauma bays and the potential to serve as postanesthesia care units if necessary. In the event that patient assessment areas within the ED cannot be used, waiting rooms, parking areas, and other access areas can be set up outside to receive and triage these patients. A hospital-wide disaster plan should be in place to streamline this process in the event of an emergency [6].

This requires communication and cooperation among other services within the hospital. Medical and surgical teams must be prepared to decompress the ED and create space for casualties as quickly as possible.

Decontamination

Although covered in greater detail in Part 6, a decontamination area is an essential component of the trauma resuscitation environment. In the event of chemical/biological disasters or radiation incidents, a plan should be in place for wet and dry decontamination to occur outside of the main resuscitation area. An internal decontamination room that is directly accessible from the ambulance bay without entering other parts of the resuscitation area must also be available. This room must be equipped with running water, a floor drain, and a trap for contaminated water, as well as adequate storage space for personal protective equipment.

Communication

Maintaining clear lines of communication in the trauma resuscitation area is essential for maximizing efficiency and minimizing stress in this busy environment. Telephones should be available within each trauma bay and at each clerical area in order to facilitate this. Direct radio communication should be available to the local EMS services and an intercom or public address system that can reach all areas of the resuscitation area (including reception/triage and the radiology suite) [6]. Not only is communication between members of the trauma team essential, but key personnel including CT scan technicians, radiologists, and the OR teams, for example, must be notified of the patient's arrival. All key personnel involved in the care of the critically injured patient should be kept apprised of changes in the patient's condition as well as other important events as they occur. In designing the optimal resuscitation area, clear sight lines between trauma bays can be extremely beneficial when overseeing the concurrent resuscitation of multiple patients.

Communication systems that involve mobile phones, radios, and pagers are likely to be overwhelmed during a mass casualty incident. Therefore, a backup system for ensuring internal and external communication is essential. This may include a mass text message or hospital-wide email alert to disseminate critical information. In the event that all communication systems fail or are overwhelmed, alternative options include a courier service or "runners" to deliver important information. A third-party, off-site source of information, such as the Red Cross, should also be included in the mass casualty preparedness plan to prevent overloading the hospital's telephone system.

Control Center

A central medical alert center (MAC) should be in place for coordinating the distribution of critically injured patients to the closest regional trauma center. This will be dictated by the local trauma center availability. In L.A. County, for example, the MAC serves 13 trauma centers with over 20,000 trauma activations annually [7]. Communication begins when the MAC center receives a call from the emergency medical service regarding a critically injured patient. The MAC will then alert the trauma center that a patient is en route to the hospital. The trauma center should then have a system in place for announcing the arrival of the injured patient to the trauma team at any time of day or night, in order to ensure their timely arrival to the trauma bay. The MAC center is also responsible for coordinating the distribution of patients in a mass casualty incident. Coordinated and timely communication between the MAC and trauma center is essential for notifying the trauma team of patient injuries and giving all personnel adequate time to prepare.

Security Considerations

Every trauma center should ensure the safety and security of the employees, as well as the patients and their visitors. The entrances to the trauma resuscitation area must be monitored at all times and access from waiting areas to the treatment areas should be restricted. Security personnel should be immediately available to the resuscitation area in case a safety or security issue arises and have the ability to remotely monitor the remainder of the patient care areas and waiting room [8]. Access to the trauma center should be secured with an enclosed area that can be used for external triage, mass decontamination, or for high profile patient management.

The Trauma Bay

Resuscitation areas will vary in the number of individual "trauma bays" that they contain. These are often separated by movable partitions in order to maintain patient privacy but allow communication and direct sight lines in cases of multiple casualty incidents. The physical layout of a typical civilian trauma bay is shown in Fig. 10.1.

Each trauma bay should have a bed in the center that allows for complete access to the patient from all directions. The trauma bay must have adequate lighting and sufficient space to allow for movement of staff and equipment around the work area. A portable ventilator is usually located at the head of the bed, along with a large monitor that is clearly visible to all trauma team members. The monitor should be capable of displaying hemodynamic parameters including electrocardiogram (ECG) tracings, noninvasive blood pressure (NIBP),

Fig. 10.1 Photograph of the physical layout of a typical trauma bay. A bed is shown in the center of the room. A monitoring display, IV poles, and a wall-mounted ophthalmoscope and otoscope are located at the head of the bed. Equipment and supplies are located on clearly labeled shelves at the back of the room. Off to the *right*, there is a workstation containing a computer and forms for documentation, and to the *left*, disposal containers for used needles and other sharp objects

pulse oximetry, respiratory rate, and body temperature [9]. Lab values including thromboelastography (TEG) tracings can also be projected for the team to see. Each bed space should be equipped with a wall-mounted ophthalmoscope and otoscope and might contain infusion pumps, fluid warming devices, rapid infusion systems, and a portable monitor/defibrillator. At LAC+USC, a boom-mounted ultrasound machine is located at the head of the bed in each trauma bay, allowing for immediate focused assessment with sonography for trauma (FAST) and eFAST during the initial assessment of the patient.

Each trauma bay must be equipped for the active resuscitation of at least one patient. If the surge capacity plan involves housing multiple patients in a single room, redundancy in the resuscitation equipment must be considered. Equipment and supplies should be organized on clearly labeled shelves or mobile carts. Mobile carts allow for convenient one-stop shopping and minimize wastage of actions and time of the trauma team. These might include an airway cart, surgical procedure cart, and an IV access cart [2]. The airway cart contains equipment such as laryngoscopes with various blades, masks, bag-valve-mask devices, suction devices, carbon dioxide detectors, stylets, and endotracheal tubes of different sizes. Equipment for difficult airway situations, including cricothyrotomy, should also be readily available.

The procedure cart must contain sterile gloves, masks, gowns, and eye protection, as well as equipment for the insertion of central venous catheters, thoracostomy tubes, nasogastric tubes, and bladder catheters. The cart should also contain pre-labeled sterilized trays with supplies for diagnostic peritoneal lavage, thoracostomy tubes, and resuscitative thoracotomies. These procedure carts must be checked for inventory and replenished immediately after use. The IV access cart contains the necessary supplies for the insertion of peripheral venous catheters, arterial catheters, central venous catheters, and intraosseous catheters, as well as blood sampling tubes and IV fluids. Disposal containers for used needles and other sharp objects should be accessible within each room, and a cart containing suture materials, splinting materials, and immobilization devices such as cervical collars and pelvic binders should be located nearby. Each trauma bay should contain a sink for hand washing as well as dispensers with non-sterile latex gloves, gowns, masks, face shields, and shoe covers to assist with personal protection. At LAC+USC, there is also a pneumatic tube system within the resuscitation area for the rapid transport of blood samples to the central laboratory. The use of pneumatic tubes has been found to significantly decrease turnaround times for laboratory results and to improve the overall efficiency of patient care [4].

Trauma Observation Unit Setup

A short stay or observation unit is an effective way of managing patients with an expected length of stay less than 24 h. At LAC+USC, the surgical observation unit (SOU) contains 10 beds and is staffed by nurses in a 2:1 ratio, as well as mid-level providers. It is easily accessed from the resuscitation area and is adjacent to the OR. Patients who require close serial clinical examinations as part of nonoperative management of a penetrating injury or who require resuscitation prior to operation can be moved here, decompressing the resuscitation areas.

Special Situations

Noise Discipline in Trauma Resuscitation

According to Chhangani et al., the level of ambient noise is inversely related to the coordinated activity of the trauma team [2]. A professional environment without excessive noise should be maintained at all times within the trauma resuscitation area. Keeping ambient noise to a minimum will minimize patient anxiety, improve team efficiency, and allow the trauma team leader to be heard by all those participating in the resuscitation. This is particularly important in mass casualty incidents.

Resuscitation in the Operating Room

The unstable patient with a clear mechanism of injury requiring operative intervention may bypass the trauma bay and proceed directly to the trauma operating room. The trauma OR is ideally located near or adjacent to the resuscitation area to minimize transportation times and should be appropriately staffed by a dedicated team that includes an anesthesiologist, circulating nurse, scrub nurse, and additional OR personnel depending on the nature of the injury. The trauma OR should be immediately available 24 h per day and be prepared to accommodate an unstable patient with little advanced notice [10]. In addition to the equipment found in the trauma bay, the trauma OR also contains an anesthesia machine, multiple infusion pumps, autotransfusion devices, and access to sterilized surgical supplies.

Hybrid Operating Rooms

Over the past several years, hybrid operating rooms have emerged that combine interventional and surgical procedures for the care of the critically injured patient. The hybrid OR, equipped with a fixed C-arm and angiography table, allows for specialized interventions to be carried out simultaneously and therefore maximizes efficiency [11–13]. Unstable patients with significant hemorrhage from pelvic fractures, for example, can be transported to the hybrid OR for pelvic packing and internal iliac artery control followed by angioembolization without ever leaving the operating room. The layout of a typical hybrid trauma OR is depicted in Fig. 10.2.

Fig. 10.2 Photograph of a typical hybrid operating room at a level I trauma center. The OR contains the same equipment and materials as the trauma bay all arranged around a centrally placed operating room table. The hybrid OR is also equipped with a fixed C-arm and angiography table that allows for specialized interventions to be carried out simultaneously

Conclusions

A well-designed trauma resuscitation area facilitates the rapid mobilization of personnel and resources and streamlines the evaluation, resuscitation, and treatment of critically injured patients. The physical design of the space not only impacts staff workflow and communication but also directly affects all steps of the patient triage and resuscitation. In this era of cost containment, building flexibility into the design will ensure maximal efficiency in usage of the space while allowing for rapid ramp up in case of mass casualties. As future technological advances occur, flexibility in design will also allow the resuscitation area to adapt and continue providing optimal care.

Key Points

- The design of the resuscitation area should allow for efficient patient inflow and outflow.
- The entrance to the resuscitation area should be well lit with designated "drop-off" zones; it must be secure and large enough to be used as an external decontamination and triage area in case of a disaster.
- The physical plan of the trauma resuscitation areas should allow for temporary expansion as part of a surge capacity plan.
- An observation unit is an effective way of managing patients who require close serial examinations or resuscitation prior to surgery and can decompress the resuscitation area.
- Preparation is critical, and the resuscitation area should include all necessary equipment and supplies for the physiologic monitoring and active resuscitation of the trauma patient.
- Communication is key, and the design of the resuscitation area must ensure clear lines of communication at all stages of patient triage and resuscitation.

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11 Quality Improvement and Trauma Quality Indicators

Nori L. Bradley, Selena Au, and Sandy Widder

Introduction

> Measurement is the first step that leads to control and eventually to improvement. If you can't measure something, you can't understand it. If you can't understand it, you can't control it. If you can't control it, you can't improve it.
>
> —H. James Harrington

The level of quality in the current healthcare system has been questioned in recent years [1]. The oft-cited report "To Err Is Human" by the Institute of Medicine indicates that up to 98,000 people die annually in US hospitals as a result of injuries from their care [2]. This has been a strong impetus for the public to demand better quality from their healthcare system and their providers at an affordable cost [3]. Trauma is the leading cause of death in the first four decades of life, the fifth leading cause of death overall in North America, and a significant contributor to potential years of life lost. Overall, major trauma patients have a 20 % mortality rate, while survivors often sustain permanent disability [4]. We would argue that those involved in acute trauma care share the same attitude as the general public: that systems and provider teams can be further improved to benefit patients and improve population health.

Despite the societal importance placed on QI and the medical community's acknowledgement of the issue, there are still relatively few institutions who measure quality data in a regular, rigorous manner to determine whether changes are truly leading to improvements. Sadly, even fewer achieve prolonged success in QI. Many interventions are reactive to critical incidents or high-profile issues, and sustainability may not have been factored in during the change design. This chapter will discuss healthcare quality as it relates to trauma, current measurement systems and indicators, and the potential benefits that can be derived from contributing to a trauma data registry.

Healthcare Quality and Relevance to Trauma

A widely accepted definition states *quality of care* is "care that results in desired health outcomes and is consistent with best professional practice" [5]. In order to delineate an abstract concept like quality into a measurable framework, six dimensions of quality have been proposed under the Institute of Medicine (IOM)'s "aims for improvement" [2]:

1. *Safe*: Care in healthcare facilities should be free from harm.
2. *Effective*: Evidence-based practice should be standard of care.
3. *Efficient*: Care should be cost-effective with minimal waste in the system.
4. *Timely*: Waits and delays to care/treatment should be minimized.
5. *Patient-centered*: Care should focus on the patient, respecting personal preferences and supporting patient control during treatment.
6. *Equitable*: Disparities in care should be eradicated.

By creating specific performance measures that align with these six dimensions of quality healthcare, potential for improvement in patient care can be realized within each healthcare discipline. Performance measures may be categorized as those reflecting *structure*, *process*, and *outcomes*, relying on the Donabedian model. Briefly, structure

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refers to the physical environment of a healthcare facility, process refers to clinical interventions for a given patient, and outcome refers to the patient status after completing an episode of care. See Table 11.1 for definitions and trauma-specific examples. With respect to the IOM aims, a process measure reflecting "timely" and "effective" care would be getting trauma patients to the operating theater within 60 min. A process measure reflecting "safe" care would be the proportion of trauma patients receiving appropriate deep vein thrombosis prophylaxis. Only when we are able to define meaningful trauma quality indicators can we identify appropriate interventions and implement the art of "change management."

Trauma patients are inherently at risk for harm in healthcare. They are a unique population in that they are generally young with minimal comorbidities, but can present acutely in physiological extremis, and often are socially disadvantaged. Recent evidence reveals that trauma patients face the same challenges as other patient groups in obtaining high-quality care [6]. Great variability in clinical outcomes has been observed across hospitals that treat trauma patients, including Level I centers [7]. Even in countries with mature trauma systems, up to 50 % of major trauma patients do not receive recommended care and preventable trauma deaths still occur in hospital [8]. In Canada, adherence to ATLS guidelines appears low in rural settings [9]. Furthermore, medical errors are common in critically ill trauma patients [8]. Review of in-hospital trauma deaths has found 2.5–14 % of medical errors were preventable [10]. Thus, we would argue that the question has changed from *if* quality improvement should be part of trauma care to *how* quality improvement should be part of trauma care.

Table 11.1 Performance measures: descriptions and examples

Measure	Description	Trauma examples
Structure	Measures of the static characteristics of the individuals providing care (e.g., education, certification) and the settings where care is provided (e.g., equipment, staffing levels)	– Proportion of ATLS-trained healthcare providers – Level of the trauma center
Process	Measures of what takes place during the delivery of care. It can reflect both appropriateness of an action (e.g., ordering the right test) and skill for properly performing the action in a timely fashion	– Obtaining a CT head for GCS ≤8 within 30 min of arrival to a healthcare facility – Proportions of patients who received DVT prophylaxis
Outcome	Measures of whether healthcare goals were achieved, which can include cost, patient satisfaction, or disease control	– 30-day mortality – Return to work within 3 months of injury

Quality Indicators in Trauma

The use of quality indicators in trauma care is an evolving process. Ideal quality indicators should have high reliability, sensitivity, and specificity, while process measures should have empirical links with patient outcomes [11]. With respect to trauma, ideal quality indicators should apply to a significant number of cases, rely on current and best practice, consider a specific/appropriate population, include a risk adjustment strategy, and reflect outcomes other than mortality [12]. Most health care providers have experienced cases where good patient outcomes have occurred despite poor care (i.e., faulty process or inadequate structure) and cases when poor outcomes have occurred despite optimal care in well-equipped facilities. Thus, any measure that assesses quality must be designed such that it truly captures the aspect of the healthcare system/patient care that it is thought to capture.

The American College of Surgeons Committee on Trauma (ACS-COT) used expert consensus to create an initial set of quality indicators (audit filters) in 1987 to facilitate quality improvement from the peer review process [6]. Since then, a plethora of indicators have been implemented in a variety of jurisdictions, which allows for standards to be set and for other organizations to work toward in order to improve trauma patient care. In a recent survey of trauma centers in Canada, the USA, and Australasia, 10,587 quality indicators were identified from 242 institutions, including 1,102 unique indicators. The ten most common quality indicators identified are listed in Table 11.2 [13].

Several limitations in the reported quality indicators were noted. Most quality indicators were not well specified; a descriptive statement was included, but lacked detail regarding data elements or construction of the measure, which impacts reliability and validity of the indicator.

Table 11.2 Ten most common quality indicators identified from 247 trauma centers

Quality indicator	Percentage of centers
Appropriate admission service/physician	53
Hospital mortality	43
Secure airway in comatose patient	40
Time to laparotomy	39
Scene time	38
Time to craniotomy in severe traumatic brain injury	36
Length of stay	35
Reintubation within 48 h of extubation	34
Nonsurgical management of gunshot wound	32
Unplanned return to operating room	30

From: Santana MJ and Stelfox HT. Quality indicators used by trauma centers for performance measurement. *Journal of Trauma* 2012; 72(5):1298–1303 [13]. Used with permission from Wolters Kluwer Health

Furthermore, not all aspects of trauma care were captured with these measures. While many indicators reflected hospital process and outcomes for trauma care, few measured prehospital care and even fewer measured posthospital care or secondary prevention. In all phases of trauma care, structure-based quality indicators were rarely used. With respect to the Institute of Medicine's six aims for improvement (described earlier in this chapter), patient-centered care and equitable care were measured by less than 1 % of the 10,587 quality indicators reported [13]. Process measures put forth by ACS-COT have also been questioned in their ability to reflect patient outcomes [14]. A recent review of current ACS-COT quality indicators found those that are strongly associated with clinical outcomes may lack face validity to identify poor-quality care for complex multitrauma patients [7]. It is clear that gaps exist in the current assessments of trauma quality.

Despite these gaps, several initiatives in North America show promise to advancing the measure of quality in trauma. In 2006, the American College of Surgeons created the Trauma Quality Improvement Program (TQIP) to move forward from ACS-COT audit filters and provide reliable, high-quality, and risk-adjusted data for mortality rates and ten common in-patient complications, e.g., deep venous thrombosis, across participating trauma centers [15]. Rigorous standardization of the National Trauma Data Standard (the means by which hospital data is collected) has allowed TQIP to provide benchmarking measures such that individual trauma hospitals can compare themselves to other centers and identify areas of strength and weakness in prespecified areas [15, 16]. As well, there is the ability for institutions to network in order to facilitate and offer mentorship around some of the QI initiatives. This allows institutions to focus QI efforts in addressing areas of substandard performance. It also highlights best practices of care, which can be shared among institutions, and can influence funding in pay-for-performance models. Currently, over 200 institutions in North America are using TQIP [17].

At this time, TQIP relies on ordinary logistic regression to compare institutions. Ongoing work in Quebec, Canada, to assess interhospital mortality suggests that hierarchical logistic regression may be a better method to assess hospitals given the relationship among patients treated at the same institution [18]. However, this method is more complex than ordinary logistic regression and the implications of widespread implementation are still being evaluated. Related work suggests that risk-adjusted models for length of stay [19] and unplanned readmissions [20] are valid quality indicators to reflect acute trauma care. These models are based on routinely collected registry and administrative data and can be used to drive performance improvement. Another method to increase reliability of trauma quality indicators has been the development of composite measures for predicting mortality.

Table 11.3 Quality indicators included in composite score [21]

Quality indicator
Team activated for major trauma patients
Fixation of femoral diaphyseal fracture in adult trauma patients
Head CT received within 2 h
GCS score <13 and head CT received within 2 h
Sub-/epidural hematoma receiving craniotomy within 4 h
Cranial surgery <24 h
Abdominal surgery <24 h
Interval <8 h between arrival and treatment of blunt, compound tibial fracture
Laparotomy performed less than 2 h after arrival at ED

Computation of composite scores, based on multiple indicators, takes interactions between processes into account and may better reflect the complexity of trauma care [21]. Composite measures have been used to identify top hospital performers in management of medical issues such as congestive heart failure, pneumonia, and acute myocardial infarction [22]. In the setting of trauma care, performance on nine process measures, e.g., head CT within 2 h of injury, combined as a composite measure successfully predicted mortality rates at the individual hospital level (Table 11.3) [12].

The TQIP program and development of composite measures are the first steps to improve the validity of quality indicators in trauma. Unfortunately, many of these initiatives focus on identifying factors associated with in-hospital mortality. Development of trauma systems over the past four decades has contributed to significant reductions in mortality. However, decreases in mortality rates do not necessarily reflect lower morbidity rates and may miss deficiencies in caring for those who survive [23]. Several groups [10, 18, 24] have shown that other important aspects of trauma care are worthy of—and deserve—rigorous assessment. These groups advocate for additional outcome measures in order to evaluate the quality of trauma care, such as health-related quality of life [10], length of stay [19], and unplanned readmissions [20]. Hopefully, as the science of QI continues to evolve and lessons can be learned from the refinement of mortality-based quality indicators, a more standardized and complete approach to QI in trauma care can be established. As leaders and advocates for the provision of trauma care, it is our responsibility to participate in this process.

Quality indicators help us establish that there is a problem, but these measures do not tell us how to fix the problem or whether or not the changes we implement are actually leading to an improvement. Here is where knowledge of quality improvement science can be of tremendous value. QI fundamentals, which include defining the problem, identifying the root cause, and use of the Plan–Do–Study–Act cycle to operationalize change, underlie how we can move forward to standardize and improve trauma care.

Quality Improvement

Quality improvement (QI) is an approach that originated in industry during the 1920s and has been more recently applied to the healthcare system. It is both a method and cultural movement for all stakeholders including healthcare providers, management, patients, and families to evaluate and improve processes of patient care to achieve better patient outcomes, system performance, and professional development [25]. Before initiating any improvement initiatives, stakeholder engagement is vital to understand where the problems are and what changes are high priorities for the organization. Alignment with organizational needs is critical for ongoing success. Although a variety of QI processes exist to evaluate a system for improvement, we will be focusing on a commonly used model for improvement: the Shewhart/Plan–Do–Study–Act (PDSA) cycle (Fig. 11.1) [26]. Before performing a PDSA cycle, we must define the project aim, components to measure, and intervention for change by answering three key questions: (1) What are we trying to accomplish? (Aim) (2) How will we know that a change is leading to an improvement? (Measure) and (3) What change can we make that will result in improvement? (Change). Once a change and its measure are defined (Plan), it is tested on a small scale in a real setting (Do). Successes and failures of the intervention are analyzed with frequent modifications made in response to observations (Study). The intervention is tested repeatedly with these improved variations (Act) before implementing on a broader scale. While scientifically grounded, such an approach is inherently different from that used in conventional randomized controlled studies because modifications to the intervention are continuous and we begin to make improvements in the system before the intervention itself is perfected. In this way, a PDSA cycle allows us to exact change quickly while adapting interventions to suit the needs of the users and system. The PDSA model for improvement can be seen in the following example: Plan, to improve compliance with administration of deep venous thrombosis (DVT) prophylaxis in trauma patients; Do, a monthly educational seminar to new residents orienting on the trauma service; Study, audit charts on a weekly basis and determine compliance rates after 3 months; and Act, compliance rates have not improved to targeted goal, prompting another change intervention, e.g., a standardized order set including DVT prophylaxis. The cycle is then repeated until the target goal is achieved. Failure of quality improvement projects is most often due to lack of rigorous testing and introduction of change too early in the process. When initiating a PDSA cycle, it is important to develop a family of performance measures. In addition to choosing an outcome and process measure (e.g., percent of trauma patients with pulmonary embolism complications and percent of patients getting DVT prophylaxis, respectively), one must also consider a balancing measure. A balancing measure is an outcome that is measured to ensure that the impact of changes to one part of the system does not cause changes (positive or negative) to another aspect of the system (e.g., increased bleeding with higher rates of DVT prophylaxis).

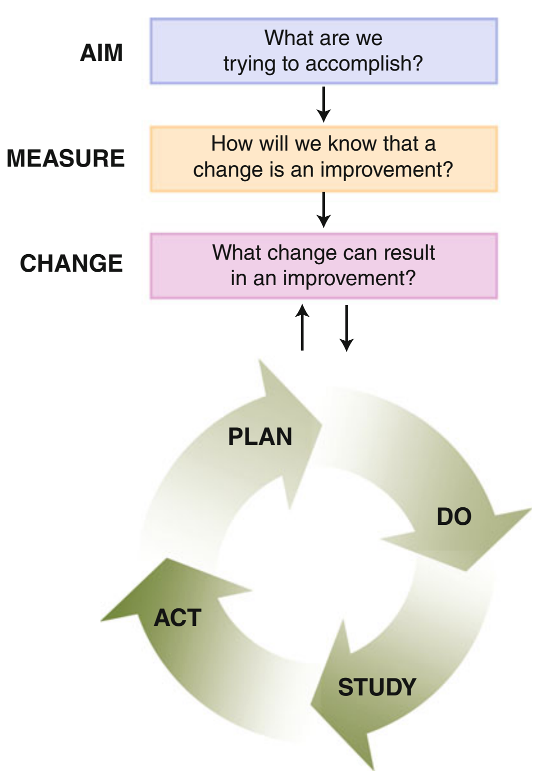

Fig. 11.1 Shewhart/Plan–Do–Study–Act cycle

After choosing appropriate measures, an improvement plan requires that data is collected on a regular basis and audited. Results should be analyzed in meaningful intervals so that data is displayed over time. Quality tools such as run charts or control charts, which are beyond the scope of this review, are powerful methods to visualize the impact of a change.

In order to ensure small wins and early successes to drive larger organizational projects, several principles should drive any QI initiative:

1. Select an issue that is feasible and within your area of influence.
2. Choose targets that are easy to measure at baseline and over time.
3. Ensure that data is being collected and reviewed on a regular basis.
4. Find commonalities and relate microsystem quality data and projects to organizational initiatives in order to help build support for future projects.

Opportunities for Improvement

For those individuals and institutions new to QI initiatives, we will leave you with several clinical questions as examples to reflect how the Institute of Medicine's six aims for improvement might be applied to trauma care at your institution:

1. *Safe*: What is the mortality rate and the adverse events rate for trauma patients treated at your facility?
2. *Effective*: Do all trauma patients with a GCS $\leq$ 8 get a head CT within 2 h of injury? What is the rate of compliance with DVT prophylaxis in trauma patients at your institution?
3. *Efficient*: Is there a significant duplication of imaging and tests for patients transferred from other facilities?
4. *Timely*: How long does it take for trauma patients within your catchment area to obtain definitive care?
5. *Patient-centered*: What proportion of patients and families are provided with clear information during transitions between facilities or hospital departments?
6. *Equitable*: Are certain trauma patient populations that you treat (e.g., rural patients, First Nations, the homeless) having worse outcomes that may be attributable to disparities in care?

Approaching these questions first requires your institution to have a trauma data collection system or contribute to a trauma data registry. With a data system in place, regular audits and rigorous quality improvement studies can help you find the answers. Ongoing critical evaluation of your current level of care will allow you to identify opportunities to improve quality of trauma care for your patients.

Key Points

- In order to determine whether there is improvement occurring and whether those improvements are contributing to delivery of quality patient care, it is important to not only have measurements in place but to analyze data regularly and share this data in a timely manner with members of the trauma team.
- Quality measurements should align with the six dimensions of quality healthcare (safety, effectiveness, efficiency, timeliness, patient-centeredness, equitability).
- Use of trauma quality indicators can help with quality improvement. Ideal quality indicators should apply to a significant number of trauma cases, rely on current and best practice, consider a specific population, include a risk adjustment strategy, and reflect outcomes other than mortality.
- Using the Shewhart/Plan–Do–Study–Act cycle enables rapid changes to occur over a short period of time, to help drive improvement strategies. In order to ensure sustainability, it is important that quality improvement projects are introduced and implemented in an effective fashion; the project is one that is important to stakeholders, is in line with organizational strategies, and is regularly audited.

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Putting It All Together: Quality Control in Trauma Team Training

12

Corry Jeb Kucik and Polly A. Haskins

Introduction

Quality control, a term originating in business and manufacturing but increasingly being applied to "production lines" in medicine, is a process by which companies review the quality of all the factors contributing to their performance. The following factors are important to achieve and maintain quality: standards (recognized best practices), review of individual cases, individual qualifications and competence, healthy team interactions and relationships ("esprit de corps"), and overall organizational culture or climate. A rigorous, supportive system will catch and correct most mistakes in patient care; however, a deficiency in any single aspect of these criteria can contribute to conditions leading to an avoidable adverse outcome [1].

Just as in business, medicine's "product" is increasingly being evaluated by "inspectors" (The Joint Commission, representatives of the insurance industry, state and federal health regulators, litigation attorneys, and others). Careful attention to detail and willingness to engage in the betterment of teamwork and communication are absolutely required to achieve optimum performance of a trauma team, which may mean the difference between life and death for our patients, and continued employment for teammates and ourselves.

As introduced in Chap. 11, the Institute of Medicine's (IOM) "six domains of healthcare quality" serve as a useful educational tool to consumers (patients) on the quality of care they will receive, as well as an excellent guide to providers (physicians, nurses, techs, and the teams they comprise) as to the criteria upon which their performance will be "graded" by the healthcare system [2, 3].

As one can see, the IOM continues to support the assertion that safe and effective care is and will remain the sine qua non of all patient care, including that of trauma. However, other quality metrics such as efficiency, patient satisfaction, and culturally appropriate care, while seemingly secondary, will increasingly drive healthcare decisions and may aid in the optimization of care provided to trauma victims.

Defining Quality in the Team Context

Trauma and critical care teams have been "interdisciplinary" much longer than this term has been in use. Interdisciplinary or transdisciplinary teams are defined as multiple professionals working together under a shared model with a common language [4]. Team-based work is essential in trauma and critical care due to several factors including:

1. Increasing complexity of skills and knowledge required to provide complex care to patients
2. Increasing specialization in health professions and a corresponding fragmentation of disciplinary knowledge, resulting in no single healthcare professional being able to meet all the complex needs of the patient
3. Policy emphasis on multi-professional teamwork and development of shared knowledge
4. Pursuit of continuity of care moving toward continuous quality improvement

Cross-disciplinary collaboration in the realm of patient safety has been emphasized in the IOM's "To Err is Human: Building a Safer Health System [5]." One of this report's landmark recommendations advocated that "Patient safety programs should establish interdisciplinary team training programs for providers that incorporate proven methods of team training, such as simulation." The report further asserted that considering how people interact with each other

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in teams, as well as counting technology as a member of the work team, should be integral in designing safer healthcare systems. To that end, Nancarrow et al. proposed ten "interdisciplinary team competencies" to guide the formulation, operation, and quality control of such teams [6]:

1. An identified leader who provides clear direction and vision for the team as well as listening, support, and supervision
2. Incorporation of a set of values that provide direction for team's service, which should be visible
3. Demonstration of team culture and an interdisciplinary atmosphere of trust, wherein contributions are valued and consensus fostered
4. Appropriate processes and infrastructure to uphold the vision of service (communication, equipment, referral, transfer to next echelon of care)
5. Provision of quality patient-focused services with documented outcomes, utilizing feedback to improve quality
6. Use of strategies that improve intra-team communication, collaborative decision making, and effective team processes
7. Sufficient team staffing to integrate appropriate mix of competencies, skills, and personalities to meet needs of all patients
8. Recruitment of staff who demonstrate interdisciplinary competencies including team functioning, collaborative leadership, communication, professional knowledge, and experience
9. Promotion of role interdependence while maintaining respect for individual roles and autonomy
10. Facilitation of personal development through appropriate training, rewards, recognition, and career opportunities

The Military-Medical Overlap: Some Quality Control Principles in Trauma Teams

Successful teams display five characteristics: *commitment*, *common goals*, *competence*, *performance consistency*, and *communication* [7]. Commitment by all members, both to a common goal and to each other, can be cultivated by clear expectations, unequivocal leadership, history of shared experiences, and basic trust and respect for each other's diverse skills. Experienced, effective teams adapt to changing patient requirements, can anticipate clinical activities, monitor interventions, are familiar with each other's roles, and offer corrective action when necessary. In such teams, suggestions and corrections are welcome from all, regardless of rank or station, and are made without fear of reprisal.

Table 12.1 Crew resource management principles and analogous TeamSTEPPS principles [12, 13]

Decision making	Leadership, mutual support
Assertiveness	Leadership, attitudes
Mission analysis	Situation monitoring, attitudes
Communication	Communication
Leadership	Leadership
Adaptability/flexibility	Attitudes
Situational awareness	Situation monitoring

While teaching any of the multitudes of comprehensive leadership training and team management models is beyond the scope of this work, some important principles can be easily elucidated for effective incorporation in almost any trauma team. Many of these principles have been developed not only in industry but also in "high-reliability organizations [8]" such as commercial aviation, aircraft carrier flight decks, nuclear power reactors, and the like. The ability to process large amounts of information quickly and then act effectively on it (faster than one's enemy, in military parlance) has been codified in the "Boyd cycle" or "OODA loop" (Observe, Orient, Decide, Act) advocated by air combat pioneer Col. John Boyd [9]. Models such as aviation's Crew Resource Management (CRM) sprang from such innovations and have been effectively adapted into medical practice, including the Team Strategies and Tools to Enhance Performance and Patient Safety (TeamSTEPPS) [10], both of which deserve mention as proven and effective methods to ensure patient safety, full engagement of the trauma team, and, resultantly, enhanced quality control (Table 12.1).

A variation on CRM, Trauma Crew Resource Management (TCRM), evolved from the UK Ministry of Defense aviation training CRM programs of the 1980s and emphasized communication and teamwork to increase safety of military air operations. TCRM was initially adopted by anesthesia teams in immersion-type simulation training, utilizing fast-moving scenarios, debriefing, and analysis of team performance. CRM courses have now been adapted to trauma and critical care teams and teach essential skills such as adaptability; task prioritization; shared situational awareness; workload distribution; team communication before and after patient arrival; mobilization of resources in the trauma bay, operating room (OR), intensive care unit (ICU), and diagnostics; performance monitoring and cross-checking of data; command, communication, and feedback coordination; leadership and management of team member followership; willingness to challenge each other; and conflict resolution skills [11]. With training, processes become planned and standardized, and each member knows not only his or her own responsibilities but also those of his teammates and can anticipate actions due to repetition and practice.

TeamSTEPPS evolved from the Joint Commission's 2008 National Patient Safety Goal 16: improve recognition and response to changes in a patient's condition. It was developed by the Agency for Healthcare Research and Quality (AHRQ) for training teamwork tools and strategies to healthcare professionals (available at http://teamstepps.ahrq.gov/). Several important innovations of the program have already reached prominence in medical practice and are increasingly being incorporated into trauma care. Rapid Response Systems (RRS) were the inaugural medium used to incorporate inter-team knowledge, "boundary spanning" transition support, and communication utilizing a specific framework. Inter-team knowledge supports continuity of care between different levels or types of care within the hospital (e.g., from the OR to the Postanesthesia Care Unit) and expects that team members will have an understanding of roles and responsibilities within the team. The "SBAR" framework provides a standardized communication format for passing patient information and consists of the components situation (what is going on with the patient?), background (what is the clinical background or context?), assessment (what do I think the problem is?), and recommendations/request (what would I do or ask that my teammate do?). Evidence supports the positive impact of implementation of RRS and TeamSTEPPS [10], and various "how-to" guides are available to assist [12, 13].

MedTeams, a training medium developed by the Society of Trauma Nurses, similarly converts these concepts to apply to healthcare. The curriculum teaches teams to clarify the medical situation, use a callback system to enhance communication, support a culture of challenge (validate decisions by team members), delegate tasks to specific people, and communicate the plan to the entire team [14].

Individual Qualifications and Team Training

Appropriate individual education, training, and baseline qualifications are a requisite starting point for building the successful trauma team. However, individual qualifications alone are not enough; indeed, poorly coordinated or even conflicting experts in their field may produce inferior patient outcomes when compared to a well-rehearsed team whose individuals, while competent, may be mediocre by comparison. Emergency physicians, trauma surgeons, anesthesia providers, additional consultants, nursing staff, respiratory therapists, and medical technicians (like the Navy Hospital Corpsman) must converge upon the patient in a well-choreographed effort to save a life. No single specialty can do it all, and trauma is indeed a team sport [14]. A team is essentially defined as a small group of people with corresponding complementary skills, all working together to achieve a common goal. Effective teams are scalable and dynamic, performing both independent behaviors as well as interdependent and coordinated series of tasks [15].

Team-Based Principles

Again, a full discussion of principles such as *leadership*, *adaptability*, and *assertiveness* is included in earlier chapters. Many of these characteristics are not easily taught but must be developed through experience, introspection, and careful study. Thus, there is a need for simulations, drills, reviews, and feedback. Indeed, some principles, most notably leadership and decision making, are the focus of advanced study in many fields. While some have argued that traits such as leadership and adaptability are innate, growing evidence [16] suggests that even among those not so inclined, these skills can at least to some degree be learned. In many ways, leadership will "declare" itself in a trauma team, and team members will adapt to its presence (or absence) over time. Anyone who wishes to exert leadership within a trauma team should expect not only to know his or her field well but should also commit to continuously revisiting the study of leadership in adversity, human behavior, and communication.

Maintaining good *situational awareness*, as well as a healthy appreciation for how quickly the clinical (or operational) situation can change (*adaptability*), is critical, especially in a combat or mass casualty environment. The trauma team must not only anticipate the likely course of a specific injury but also respond seamlessly when the information changes—especially for the worse—and must do so in a non-accusatory manner if trust and communication are to be reinforced. Situational awareness generally involves three (or four) levels: perception, comprehension, and projection. *Perception* encompasses monitoring, cue detection, and simple recognition and leads to an individual awareness of current objects, events, people, systems, and environmental influences. *Comprehension* involves integration of the many varied perceived components, as well as an appreciation for how these factors may influence individual or team goals, objectives, and outcomes. *Projection* is achieved through taking the knowledge gained from perception and comprehension, and then extrapolating their likely impact on the patient or operational environment in a timely manner [17]. Personnel and supply status, the likelihood of additional incoming casualties, operating room availability, blood supply, en route care capability, evacuation assets, weather conditions, and current tactical or security situation must all be within the "scan" of the modern trauma team's situational awareness, particularly when making patient care decisions in a deployed environment [18]. The trauma environment, much like the combat setting, implies dynamic conditions that routinely change in a split second, and therefore, situational awareness must become a product of the team, whereby "distributed cognition" becomes the team's expected norm, significantly augmenting their previous performance.

Good *communication* naturally lends itself to distributed situational awareness, augmented trust, and teamwork. Familiarity as a team can also lead to the ability to "read" unspoken communication factors; body language, task distribution, command structure, team history, and individual personality considerations all play a role. It is broadly documented that errors in communication are responsible for approximately 60–80 % of all healthcare errors. Communication between team members must be clear and unambiguous and is most effective when members feel respected and empowered to participate [19].

Communication must be in a language that all team members can understand and not be "profession specific" (sometimes interpreted as condescending). Ideally, the communicator will make eye contact, will stop distractions or other tasks if possible, and will check understanding on the part of the intended receiver (e.g., by having them repeat back the information or request that was passed), all while minimizing any emotional factors. Unequivocal ("autocratic") communication from a defined trauma team leader has been shown to contribute to improved team coordination, ATLS adherence, and secondary survey [11] performance and is often called for during stressful phases of initial evaluation and resuscitation. Conversely, once the patient has been stabilized and admitted, the multidisciplinary trauma/critical care team (intensivists, nurses, respiratory and physical therapists, pastoral care, interpreters, and many others) can ideally operate under a more collaborative governance [19].

Most successful team leaders promote "psychological safety," encouraging all team members to express their observations and opinions without fear. This, however, must be balanced with the responsibility of each member to be accountable for and competent in their actions and to perform them well in a stressful, fast-paced environment. Team-wide familiarity with each member's skillsets, norms, and role expectations increases cohesiveness, communication, and ultimately performance. Additionally, leaders who utilized cross-disciplinary leadership, collaborative decision making, and clear communication tended to benefit more from team feedback and inspire motivation, leading to overall improvement in team performance [15]. *Flexibility* of all members between the autocratic (trauma team leader) and the empowering (intensivist leader) styles reflects trust and suggests a "flat hierarchy," one in which the leader is part of the interdisciplinary team, information is disseminated without restraint, and all members regardless of rank or position can express concerns or make suggestions [20]. Taking full advantage of the abilities of team members to communicate, both within and external to the team, will improve team performance. For instance, nurses are a valuable asset as they bring not only a highly developed clinical skill set but also serve as key communicators both within the team and to ancillary staff and family. Nurses demonstrate collaboration, credibility, compassion, and coordination when communicating with the healthcare team [21].

As mentioned earlier, communication in the trauma bay must be clear, direct, and often autocratic in order to avoid confusion and ensure tasks are accomplished expeditiously. *Communication errors* are often divided into "sender" and "receiver" errors. Sender errors include those pertaining to delivery (too quiet, too fast), clarity (who's the intended receiver?), context confusion (which arm?), detail and timing questions (dosages and order of ACLS drugs), lack of nonverbal communication (sense of urgency), and failure to check to see if directions were understood. Receiver errors include a lack of preparation to receive message, preconception as to what the message is (bias), distractions, task saturation, and failure to confirm for accuracy. Noise, lighting, ancillary equipment, communication devices, additional people, the need to protect certain patient information, interruptions, and other occurrences (both clinical and security related) can all degrade communication flow. Emotional factors such as staff anxiety about the situation/role/rank, disagreements with other team members, personal concerns at home or even hunger, feeling tired, or even being late for duty can also influence the receiver's ability to process information. Increased training, experience, and team familiarity can mitigate these factors over time [22].

Other Factors Affecting Team Performance

There are many other factors that may adversely affect trauma team dynamics and the work they produce [11]. Individual (or human) factors such as clinical knowledge, fatigue, external workload demands, sleep deprivation [5], stress, personal concerns, and patient deaths may cloud judgment or contribute to task saturation. Noise, lighting, temperature, motion (e.g., on a ship or aircraft), noxious fumes (e.g., field generators, vehicle exhausts), administrative distractions, tactical situation, and physical/space constraints may all impinge on the care environment. Equipment factors such as maintenance, familiarity, usability, and the need for personal protective equipment (e.g., infectious disease or weapons of mass destruction (WMD) concerns) can degrade performance markedly. Policy and procedures, documentation, staffing demands, safety, pressures to produce, etc. comprise the organizational climate, which can in turn influence morale and work ethic. A high staff turnover, over-reliance on short-term staff, and poor organizational management can lead to a lack of collective focus and have negative influences on teamwork [15] and effectiveness.

The "problem physician" (or other team member) is a dreaded contingency that may cause interpersonal problems, avoidance, suboptimal team performance, and even legal issues. Such issues may stem from personal or marital problems, feelings of insecurity or superiority, substance abuse, or even psychiatric diagnoses. Dealing with difficult personalities is never easy, but again, the team's preparation can make dealing with such problems much more effective. Getting the team member the help he or she needs quickly and in a non-accusatorial fashion should be the team's collective goal. Knowing both internal (e.g., chaplain, psychiatry, risk management) and external (financial or marriage counseling, substance abuse treatment) resources before a problem presents offers the best chance for good outcomes for all involved.

Continuous Improvement Processes

Finally, effective trauma teams will pursue some form of feedback incorporation in order to iteratively improve their performance. Several methods exist to accomplish this goal, including simulation, videotaped review, performance metrics measurements, and iterative incorporation of best practices into a set of guidelines.

Several studies demonstrate that patient *simulation* teaches and reinforces clinical skills, decision making, cooperation, leadership, and communication in a safe and increasingly realistic environment [5, 14, 23] and calls for feedback at the end of training sessions to encourage continuing improvement. Clinical training and education are essential to cultivate a culture of safety in healthcare. Moving forward, computerized simulators plus CRM principles may be incorporated into all aspects of transdisciplinary team training courses. Simulation training can help trauma teams overcome these challenges and should concentrate on meeting these specific competencies and practice team decision making [10]. Advanced Trauma Life Support (ATLS), Tactical Combat Casualty Care (TCCC), and Trauma Nursing Core Course (TNCC) are all examples of clinical skill-based training that utilizes patient simulation scenarios to teach decision making and basic initial resuscitation skills. "Train in teams those who are expected to work in teams [5]."

Video analysis of trauma team performance provides real-time feedback and allows reviewers to analyze individual performance, teamwork/communication, and leadership, as well as adverse events that may affect team performance. Video review can be utilized as a tool for quality assessment and to determine whether teams are following "best practice" guidelines (ATLS, JTS CPG's). In the future, process (activities) and patient outcomes can be identified and measured using videotaping resuscitations and can be translated into trauma team performance metrics [10]. Patient confidentiality/medicolegal and logistical/resource issues are some of the barriers to videotape review of trauma resuscitations.

Performance tools and metrics, such as the Trauma Team Performance Observation Tool (TPOT), can be used to assess leadership, situation monitoring, mutual support and teamwork, communication quality, and overall team performance [24]. The evolution and incorporation of best practices into *standards and checklists* have become proven and well accepted [25] (and even expected) as their use has entered popular literature [26] and will likely continue to grow as a benchmarking measure in trauma care. Many organizations are compiling, publishing, and iteratively revisiting/revising checklists and guidelines, fine-tuning their recommendations as evidence accumulates. One such system that has grown from recent conflict is the US military's Joint Trauma System (JTS) Clinical Practice Guidelines (CPGs), available to the public online at http://www.usaisr.amedd.army.mil/clinical_practice_guidelines.html. Based on a significant body of evidence from trauma cases in both Iraq and Afghanistan, the CPGs undergo periodic review and continuous process improvement, and where applicable, their tenets have even begun to influence civilian practice, for instance, with the concept of damage control resuscitation.

Conclusion

The importance of monitoring quality, from all aspects and vantage points, cannot be understated in trauma team dynamics. The standardization of best practices, timeliness of interventions, effectiveness of communication, and continuous improvement through avenues such as simulation will all coalesce into the early recognition of clinical outliers and the mitigation of unnecessary variance and avoidable adverse outcomes. Improved team performance and outcomes-based metrics will become increasingly mandatory in a resource-constrained practice environment.

Key Points

- Quality control is the process by which all factors contributing to a performance are systematically reviewed.
- Successful teams display five characteristics: commitment, common goals, competence, performance consistency, and communication.
- Effective trauma teams will pursue some form of feedback incorporation in order to iteratively improve their performance.

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Part III

Trauma Resuscitation

Trauma Resuscitation

13

John B. Kortbeek

Epidemiology of Trauma

Throughout history, injury, both intentional and unintentional, along with infectious diseases has been the leading causes of premature death and disability. In the modern era injury continues to lead as the primary cause of death and disability in the first four decades of life. The impact of injury has continued to rise as developing countries adopt the automobile and motorbike in greater numbers. The World Health Organization (WHO) estimates that injury will be responsible for 1/10 deaths worldwide by 2020 with youth and young adults being the predominant victims [1]. The number of victims suffering disability following injury increases the injury burden. The economic costs, both direct health-care costs and indirect loss of productivity, are estimated in the billions.

Recognition of the impact of injury has led to significant strides in injury control. Successful programs combine and align the efforts of health-care and public health professionals, police, education, automotive, traffic and road engineers, insurance agents, and government ministries. These coalitions over time can significantly reduce the burden of injury. Successful examples in developed nations have seen reductions of up to 50 % of deaths due to injury [2]. A comparison of death rates among different countries reveals the potential reduction when efforts are successful and sustained. The four Es of injury control, education, engineering, enforcement, and effective care are a powerful combination [3]. Health-care practitioners providing daily care for the injured can increase their impact by partnering with and advocating for injury control organizations.

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Death Due To Injury

Death following injury follows a trimodal distribution. Deaths at the scene are typically due to catastrophic injury. Aortic disruption, massive hemorrhage, and brain injury, as well as complete airway disruption/obstruction, are leading causes of death at the scene. These injuries can be prevented through injury prevention and control. Patients who survive the initial event can be salvaged through prompt attention to maintaining the airway, management of pneumothoraces, and hemorrhage control. Patients who survive beyond the first day may still succumb to severe traumatic brain injury and sepsis/multiorgan failure [4, 5]. Effective initial resuscitation and management including minimizing delayed diagnosis of injuries can enhance survival. Coordinated multidisciplinary trauma teams, experienced critical care, and verified trauma systems are the foundations for ensuring survival in these patients. Modern trauma systems have reduced death and disability due to injury and shifted the trimodal distribution, minimizing initial death and disability due to delays in injury recognition and hemorrhage control.

Mechanisms

Injury may be intentional or unintentional and due to blunt, blast, and or penetrating mechanisms. Knowledge of the circumstances leading to the injury can serve as important clues to occult trauma at presentation. Patients presenting with one mechanism, for example, blunt trauma due to a motor vehicle crash, may be harboring secondary insults such as ingestion of toxic substances in cases of attempted suicide. Alcohol ingestion and toxicity are a frequent accompaniment to injury at presentation. The environment is also an important determinant of risk at presentation. Hypothermia should be suspected with prolonged prehospital times, particularly in cold climates. Smoke inhalation and carbon monoxide poisoning are often present when patients present following extraction from enclosed environments during fires.

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Blunt mechanisms have characteristic injury patterns. Fall from a height of 5 m or more is often associated with extremity, spine, and solid organ injury. Fall down greater than several stairs is associated with upper extremity, face, head, and neck trauma. Pedestrian versus motor vehicle injuries have a high risk of head and neck trauma. Frontal impact collisions tend to be high force deceleration and direct impact injuries. Young children frequently present with isolated head injury following pedestrian motor vehicle crashes. With increases in age, extremity fractures increase in likelihood [6]. With advancing age, elderly patients frequently present with intracranial hemorrhage as well as torso and extremity injury. The morbidity and mortality of injury increase significantly in the elderly [7]. In addition to diffuse severe traumatic brain injury, facial trauma, blunt aortic disruption, and both solid and hollow viscous injuries are common. Side impact collisions are usually associated with solid organ injury as well as extremity and rib fractures and chest trauma on the affected side [8–10].

Blast injuries can cause injury by overpressure injuries affecting the middle ear, lungs, and hollow viscous, penetrating injuries due to shrapnel, and blunt force trauma as the victim is struck by large objects or thrown against objects due to the force of the blast [11].

Penetrating trauma varies primarily with the speed of the projectile. Knives and low-velocity handguns tend to cause injury along the missile's trajectory. Higher-velocity weapons such as hunting and assault rifles additionally cause significant cavitation due to the associated pressure wave. This can disrupt tissues many centimeters from the trajectory and significantly increase the severity of injury [12].

Host factors are equally important when considering potential injuries. Children and toddlers present with a range of normal age-specific physiology. They often harbor significant internal injury with less apparent external trauma. Being smaller, they frequently have multiple injuries involving the head, neck, trunk, and extremities simultaneously [6]. Pediatric trauma will be discussed further in Chap. 18.

The elderly often present with significant occult injury despite seemingly minor mechanisms such as ground level falls. Injury effects may be masked, both due to the lack of extreme physiologic response such as profound tachycardia and underlying comorbidity, for example, atrial fibrillation or paced rhythms. The effects of medication may also be significant (e.g., beta blockers, anticoagulants). Newer anticoagulants, which are becoming popular in the management of atrial fibrillation, that are not reversible will undoubtedly pose profound challenges in managing trauma-related hemorrhage in the elderly in the future. Never forget that the elderly will often appear relatively well on initial presentation with dramatic deterioration over the ensuing 24–48 h [13]. Further elaboration on this topic can be found in Chap. 20.

Trauma Teams and Preparation

Physicians, nurses, and other health-care providers may encounter injured patients in a variety of settings ranging from the prehospital environment, rural hospitals with teams consisting of a doctor, nurse, and X-ray technician, to tertiary care trauma facilities with all specialties immediately available. Regardless of the setting, preparation is critical to success, and avoiding chaos during resuscitation is essential. Poor planning and execution can delay effective assessment, resuscitation, and definitive care of the injured and could also put the trauma team members at increased personal risk.

Because of local and regional variations, it is imperative that trauma practitioners understand the workings and agreements of their own local and regional trauma systems. Practitioners should be able to easily answer the following questions: Which patients can be definitively managed in your institution? What are the prehospital triage and bypass criteria? What happens when a case is mistriaged? What happens when a multi or mass casualty event occurs? What are the criteria for activating the trauma team in your hospital? What is the composition of the team? [14, 15].

A tremendous amount of work has occurred in most jurisdictions to organize responses, which answer these questions and coordinate the most effective response to maximize survival of the injured. Many of these systems seem intuitive but require continued support, organization, and advocacy. Individual practitioners should be clear on their role. They should also inform themselves of the setup and location of all essential equipment in the resuscitation areas before a patient presents. Where is the difficult airway cart? What is in it?—including special intravenous (IV) equipment, central line trays, and intraosseous equipment. Pediatric resuscitation kits, the Breslow tape? Chest tubes, insertion trays, and pleural drains? Where is the ultrasound unit for performing focused assessment with sonography in trauma (FAST) or eFAST? Does it work and where is the on switch? How are stat radiographs, operating room (OR) access, or patient transport arranged? These are simple questions that a brief walk through the resuscitation bay can answer. As the saying goes, an ounce of prevention is worth a pound of cure, and being prepared lays the stage for a smooth coordinated resuscitation with effective team leadership and a minimum of chaos and conflict [16–19].

Assessment and Priorities: ABCDE

The ATLS® course fundamentally changed the initial assessment and management of trauma [20]. The course was introduced in North America in 1980 by the American College of Surgeons following development of the prototype in

Nebraska. It standardized one safe approach to trauma care and introduced a common language. The course along with ACLS® (Advanced Cardiac Life Support) also introduced large-scale simulation to medical training. A parallel curriculum and certification program for course instructors promoted quality and consistency. By 2006, the program had expanded to over 50 countries and trained over a million physicians. Programs such as PHTLS® (Prehospital Trauma Life Support) and ATCN® (Advanced Trauma Care for Nurses) also expanded the audience for the ABCDE approach to trauma care. The principles of ATLS® are relevant to both practitioners who infrequently manage the severely injured and trauma teams in large urban trauma centers where the initial priorities are applied simultaneously. The goal is to manage the greatest threat to life first and to do no further harm to the patient.

The priorities are:

- Airway assessment and management with attention to cervical immobilization (when relevant)
- Breathing (Assessment and management of oxygenation and ventilation)
- Circulation (Assessment and management of shock states)
- Disability (Assessment and management of neurologic injury)
- Exposure (Assessment and management of the back and extremities)

The patient should be approached from the head of the bed by whoever is responsible for performing or leading the initial assessment. The findings should be clearly communicated to the team. The initial assessment and initiation of resuscitation should take 1–2 min to complete [21–23].

A typical sequence in approaching a suspected major trauma patient would be:

1. Ask the patient his or her name, apply oxygen, and if no response, proceed to more definitive airway maneuvers. Ensure the cervical spine is immobilized where appropriate.
2. Inspect and auscultate the chest, palpate, and percuss where findings warrant.
3. Palpate a pulse to establish rate and caliber. Ask for a set of vital signs including heart rate, blood pressure, temperature, and respiratory rate. Ask for initiation of two large bore IVs (16 gauge) and initiate crystalloid.
4. Check the patient's pupils. Estimate the Glasgow coma scale (GCS).
5. Expose the patient. This is a great time to log roll, remove the backboard when appropriate, and perform a rectal examination when indicated.

The key findings requiring intervention during the initial assessment are:

1. Identifying airway obstruction, either mechanical or due to coma that requires a mechanical airway
2. Identification of large or tension pneumothoraces requiring needle decompression and a chest tube
3. Identification of shock and consideration of the etiology
4. Identification of coma and especially impending herniation evidenced by a dilated pupil requiring urgent neurosurgical assessment and temporizing medical decompression
5. Identification of life- or limb-threatening extremity injuries

The most useful investigations that should be performed immediately are the chest X-ray which identifies hemopneumothoraces and a blood gas which provides an immediate estimate of adequacy of oxygenation and ventilation, the level of base deficit and serum lactate, and an early hemoglobin (Hgb). As discussed later in Chaps. 21 and 22, an EFAST (Extended Focused Assessment with Sonography for Trauma) exam is very useful for identifying potential sources of hemorrhage and identification of tamponade for patients in shock, as well as screening for pneumothoraces and hemothoraces. In the case of major blunt force mechanisms, inclusion of a pelvic X-ray is also very useful to screen for open book and vertical sheer pelvic fractures (important sources of hemorrhage) [24]. Most trauma teams will also draw a trauma lab panel including a type and screen and/or crossmatch during this process. Serum alcohol (ETOH) levels are often routinely performed to assist in assessment of depressed level of consciousness and also to aid with future trauma prevention initiatives. Drug and toxin screening may also be very useful at this stage.

Completion of the initial assessment and resuscitation including all of these investigations should be completed within 15 min or less. Clear communication of actions and findings to the trauma team will speed the process and allow earlier intervention when required. Agreeing on the sequence of these steps by team members before the resuscitation is very advantageous. Remember that the *greatest threat to life should be treated first*. A patient who presents with obvious major hemorrhage from a scalp or extremity wound should have direct pressure applied to arrest the bleeding while approaching the airway assessment. Immediate application of a tourniquet in the field for blast or high-velocity extremity wounds in the combat arena has proven lifesaving. As in all aspects of medicine, clinical judgment and experience are important.

Once the initial assessment is complete and initial resuscitation has commenced, then a quick repeat of the ABCs is very useful. At this point unless immediate surgical intervention is required, the team can proceed to a complete head to toe examination (the secondary survey) and more definitive investigations. As well, if at a site that is not resource intensive (blood products, surgical specialties, personnel), one should consider early transfer at this point.

Airway

Airway management is the priority in assessment and management. Patients with obstructed airways may have moments to live. Airway obstruction may be obvious or subtle, especially in the case of impending obstruction such as witnessed following inhalation injury in a closed space during fires. The obstruction may be mechanical due to soft tissue injury or swelling. It may be functional, associated with depressed levels of consciousness including coma [25].

In all cases where cervical spine injury is suspected or possible, the cervical spine must be immobilized during airway assessment and management. These include virtually all blunt force trauma patients with significant mechanism of injury. It also includes penetrating trauma with a trajectory that may involve the cervical spine, penetrating trauma that may be associated with unwitnessed blunt trauma, blast injuries where multiple mechanisms are evident, and patients presenting with coma where trauma is within the differential.

The best initial approach to the airway is simply to introduce yourself to the patient and ask the patient their name. The ability to respond indicates a patent airway, reasonable ventilation, a circulation adequate to perfuse the brain, and the absence of major traumatic brain injury. For patients able to speak, the most useful follow-up questions are asking them to recall what happened (events), medications, allergies, past medical history, and last meal (AMPLE history). Oxygen should be applied in all suspected cases of major trauma until a thorough assessment and impression of the magnitude of injury is complete.

In patients where airway obstruction may be impending, consider the following rules. GCS < 8 = intubate. If patients have potential impending airway obstruction with intermediate levels of GCS 9–12, inhalation injury, or neck hematoma, then ask yourself the following. What is my experience? What assistance and backup is available? Where will the patient be monitored? In cases of transport, who is traveling with the patient? What equipment do they have and how long will it take? All of these factors should be considered when planning a definitive or temporizing airway.

Once a decision has been made that the patient requires an airway, then assess for difficulty. If the patient is dying from airway obstruction and you are the only help available, then attempt intubation and/or proceed directly to a surgical airway. In other cases jaw thrust, chin lift, insertion of an oral or nasal airway, and bag mask ventilation should be performed next.

In all other cases, assess the difficulty of intubation. Remember that cervical spine immobilization will make any attempts at airway control more difficult. This may increase the need for airway adjuncts such as intubating video laryngoscopes. Forming an opinion as to the difficulty of an airway is important. If you believe it is fairly straightforward anatomy, then proceeding directly to rapid sequence intubation after pre-oxygenation is reasonable. If you believe the airway may be difficult, then wherever possible get help from an experienced colleague. Application of a variety of airway tools and devices to assist intubation is critical to success in these cases.

An easy airway typically would be recognized by a wide mouth, normal-sized and placed dentition, a large chin and jaw, and a lack of facial/neck soft tissue trauma or swelling.

Clues to a difficult airway include small mouth, chin, and jaw, significant overbite, and facial/neck trauma. The LEMON pneumonic is a useful reminder.

- Look
- Evaluate
- Mallampati score
- Observe
- Neck

In cases of an easy airway proceeding to rapid sequence intubation with an appropriately sized cuffed tube is recommended for all practitioners who have had adequate training [26].

Where a difficult airway is suspected, temporizing with bag mask ventilation and oxygen is the next step. In regional or urban institutions, asking for experienced help should be next. In rural and remote locations, bag mask ventilation until the arrival of an experienced aeromedical transport crew may be appropriate [27].

A variety of approaches and devices have been described by various specialty organizations. The best approach is one which your center and team are familiar with. A simple and inexpensive device, which often allows capture of a more difficult airway, is the gum elastic bougie. It is a long slender rod with a hook or hockey stick at the end. Simply visualize the epiglottis, hook it underneath, and advance. Correct tracheal positioning is confirmed by feeling the bougie bounce along the tracheal rings. When advanced, gentle resistance will be encountered when it reaches the secondary and tertiary bronchi. The absence of resistance and tracheal ring sensation suggests an esophageal intubation.

The laryngeal mask airway (LMA) can provide reasonable ventilation and oxygenation when this is difficult to achieve using bag mask ventilation. In experienced hands the intubating LMA can be very useful. However, the LMA does not protect the airway in cases of aspiration and may be easy to dislodge.

Recently the introduction of the video laryngoscope has revolutionized the management of the difficult airway and greatly facilitated capture on these patients. Intubation over a fiberoptic bronchoscope remains an option in the right hands.

Regardless of approach, if the airway is not captured and the patient is desaturating, proceed immediately to a surgical airway. Surgical airways will be discussed further in Chap. 17. Once an airway is placed, always confirm correct position using five techniques:

1. Look for symmetrical chest wall expansion.
2. Listen and auscultate for breath sounds.
3. Feel and palpate the chest wall for symmetrical expansion.
4. Oximetry to confirm adequacy of oxygenation.
5. Capnometry to confirm adequacy of ventilation.

Look for evidence of right mainstem bronchus intubation, due to the lesser angulation and more direct descent. Remember that an AP chest X-ray (CXR) cannot confirm the correct positioning in the trachea vis-a-vis the esophagus. Typical endotracheal tube sizes would be 7 mm for females and 8 mm for males. Average distance from the teeth would be 22 cm for females and 24 cm for males for correct tracheal positioning 3–4 cm above the carina.

Breathing: Oxygenation and Ventilation

Assessment of the chest initially by inspection and auscultation is performed early in the primary survey. A detailed complete exam should follow in the secondary survey. The goal is to confirm the presence of bilateral breath sounds. Simultaneous oximetry and, in the case of airway capture, capnometry are very useful. If breath sounds are absent, check the vitals and pulse oximeter—if both are adequate, take the time to complete the primary survey and obtain a CXR. If the patient is desaturating or hypotensive, then immediate decompression is required. While large pneumothoraces can develop in spontaneously breathing patients, pneumothoraces with positive pressure and mediastinal displacement are likely in patients' who have had positive pressure ventilation of any means.

If the patient has already been intubated and breath sounds are absent on the left, always confirm that this is not due to right main stem intubation. Simply check the endotracheal tube (ETT) position, and if it seems well-advanced, try pulling it back 1–3 cm and repeat the auscultation. When absent breath sounds are confirmed and persistent and the patient is desaturating or hypotensive, perform needle decompression in the second intercostal space, midaxillary line and follow with a chest tube (28–36 French). EFAST (see Chap. 22) exam in experienced hands can be a useful aid in detecting large hemo-pneumothoraces. Additionally, ultrasound also allows confirmation of tracheal intubation as well as differentiation between esophageal and mainstem bronchus intubation. The chest tube should be placed in the mid-anterior axillary line, above the rib to avoid the neurovascular bundle. Useful landmarks are to remain above the nipple in males and above the infra-mammary fold in females. This should avoid inadvertent injury to the diaphragm and intra-abdominal organs. A sharp trocar should not be used for chest tube placement. Good sterile technique with complete barrier precautions should be used whenever possible to mitigate the risk of empyema and its associated long hospital stays and morbidity. The chest tube should be connected to 20 cm underwater suction and outputs closely measured.

Hemorrhage of >1,500 cm^3 or >200 cm^3/h for four consecutive hours or more are indications for thoracotomy. If the chest tube drainage stops, beware, it may simply be clotted. Persistent evidence of shock and a large hemothorax on EFAST/CXR are also indications for surgery.

At the completion of the primary survey, a CXR should be obtained and a more thorough exam performed. Simple pneumothoraces, particularly those that occupy 2 cm or less from the chest wall or apex, or occult pneumothoraces (pneumothoraces seen only on computerized tomography (CT) occupying less than 1/3rd of the pleural cavity) may be observed in stable patients. Repeat CXR should be performed within approximately 6 h. Serial EFAST is potentially useful, but its role still needs to be defined. In patients requiring transport, placement of a chest tube is advised.

Additional injuries should be identified on the CXR including rib, clavicle, scapular, and vertebral fractures, wide mediastinum, pneumomediastinum, pulmonary contusion or aspiration, elevated or obvious ruptured hemidiaphragms, and subcutaneous emphysema. The presence of these abnormalities provides important clues to the severity of injury, necessary additional investigations, and treatment plans.

CT of the cervical spine is increasingly being performed for cervical spine clearance in major mechanisms of injury. CT of the abdomen and pelvis are likewise routinely performed to identify occult intra-abdominal injury. Together these tests will also identify all cases of occult pneumothorax. CT of the chest should be added to these investigations where the mechanism is high impact/rapid deceleration and could be associated with blunt traumatic aortic injury. CT of the chest combined with CT of the C-spine and CT of the abdomen pelvis allows complete reformatting and inspection of the cervical, thoracic, and lumbar spine improving both the accuracy and timeliness of spinal clearance. This is important for early mobilization, initiation of physiotherapy, and prevention of respiratory failure in patients with blunt chest trauma. In patients with multiple rib fractures and significant chest pain, mobilization and pain control should be a priority.

At the completion of the secondary survey, an electrocardiogram (ECG) should be performed. Significant cardiac contusion leading to pathologic arrhythmias and heart failure or hypotension typically occurs in patients with severe polytrauma and abnormal vital signs on presentation. Some patients present following an acute myocardial infarction or arrhythmia, which in turn led to syncope and in turn, resulted in the cause of the injuries. This should be screened for. Wide QT and QRS may be seen in patients with coexistent toxic ingestion. Troponins are of little value in acute chest trauma. In the absence of a suspected acute coronary syndrome, they are not predictive of outcomes in trauma [28].

Circulation: Recognition of Shock and Control of Hemorrhage

Once airway and breathing have been attended to and obvious sources of external hemorrhage are compressed, the vital signs should be reviewed. Quick palpation of a pulse for caliber, rate, and skin temperature provides valuable information. The majority of patients in shock following injury will be suffering from hemorrhage. Other potential causes of shock should be considered including obstructive shock due to tension pneumothorax or tamponade, distributive shock due to spinal injury (or sepsis when presentation is delayed), and cardiogenic shock due to an underlying acute coronary event/myocardial infarction. History of the event, combined with pulse, blood pressure, skin temperature, and examination of the neck veins, will usually tell the tale (Table 13.1).

Two large bore IVs should be initiated. If they cannot be inserted and the patient is in profound hypovolemic shock, then one should move onto a different form of access and consider an intraosseous line, central venous access, or a venous cutdown. Options for venous access and considerations for choice will be elaborated on in Chap. 17. Crystalloid infusion should be initiated, but the primary goal is to find and stop the bleeding or correct the underlying cause of shock. In blunt trauma with head injury, hypotension worsens outcomes and should be avoided. In penetrating trauma with ongoing hemorrhage, aggressive resuscitation prior to surgical control of bleeding may exacerbate hemorrhage and coagulopathy and worsen outcomes. Newer strategies, termed damage control resuscitation, will be considered in Chaps. 14 and 15.

If the patient is in shock and hemorrhage is suspected, then the institution massive transfusion protocol should be activated. These protocols have streamlined resuscitation and help avoid coagulopathy through early introduction of packed red blood cells, plasma, and platelets. This will be discussed further in Chap. 14. Tranexamic acid is also now an accepted adjunct. It is an antifibrinolytic which is cheap, safe, and potentially effective. Review your institution's massive transfusion protocol.

Always remember that hypotension is a late sign of shock and in the case of hemorrhage typically does not occur until the loss of one third of the blood volume or more. Early signs are anxiety, confusion, tachycardia, and narrowed pulse pressure. Repeat the vital signs to follow trends and monitor resuscitation.

The goal is to find and correct the cause of shock. In the case of hemorrhage, stop the bleeding. ATLS® teaches "blood on the floor and four more." In addition to external hemorrhage, principal sites of occult blood loss are the chest, pelvis, abdomen, and long bones. A CXR, pelvic X-ray, EFAST exam, and palpation of the extremities will review the potential sources of blood loss. EFAST exam will also demonstrate tamponade and can identify pneumothoraces.

A patient in shock due to hemorrhage or tamponade requires immediate definitive management. In the case of pleural hemorrhage or tamponade, thoracotomy should be performed. In cases of positive abdominal FAST exam, the treatment is immediate laparotomy. With long bone fractures, splinting and resuscitation should be definitive [29].

Pelvic fractures represent a special challenge. This may be associated with abdominal hemorrhage in which case initial management should be in the OR. The three patterns of pelvic trauma are lateral compression with pubic rami fractures, open book fractures, and vertical sheer injury. Lateral compression fractures are associated with pubic rami and acetabular fractures but usually do not present with massive hemorrhage. These patients often can have urethral or extraperitoneal bladder injury. Open book fractures frequently have major bleeding. Compression with a binder or sheet to temporize is useful. Vertical shear fractures usually present

Table 13.1 Shock, physical findings

Etiology of shock	Pulse	BP	Skin	Jugular venous pressure
Hemorrhagic	Rapid, thready	Low with reduced pulse pressure	Cool	Low
Tension pneumothorax	Rapid, thready	Low with reduced pulse pressure	Cool	Elevated
Tamponade	Rapid, thready	Low with reduced pulse pressure	Cool	Elevated
Spinal	Normal, slow, full	Low with wide pulse pressure	Warm	Low
Cardiogenic	Rapid, thready	Low with reduced pulse pressure	Cool	Elevated

in hemorrhagic shock. Pelvic binders are less practical and often have to be combined with axial traction. Early orthopedic consultation is very helpful. In cases where shock is present, a decision is required on whether the next step is surgery with packing and pelvic stabilization followed by angio-embolization, immediate embolization, or CT first to plan therapy followed by either surgery and or angio-embolization. This can be difficult as angiography while particularly useful for retroperitoneal or solid organ arterial hemorrhage does not stop venous bleeding and can miss low flow bleeding. In profound shock, patients should go directly to the operating room. Patients who respond to initial resuscitation may be reasonable candidates to be taken by the team to CT. Patients with partial or transient response can be divided into FAST positive or negative groups. FAST positive should have laparotomy first; FAST negative can be managed initially with angio-embolization [30–32]. These challenging scenarios will be further highlighted in Chaps. 15 and 16.

Neurogenic shock patient should receive initial 1–2 L boluses of crystalloid but then frequently require pressor therapy and ICU monitoring. Patients with coexistent cardiac pathology due to an MI or severe contusion will need to be supported in an ICU with other physiological adjuncts such as inotropes.

Remember that shock is not due to head injury. In addition a wide mediastinum with suspected blunt aortic injury is also almost never the source of hemorrhagic shock. Once the aortic adventitia gives way, death typically occurs within minutes. Look elsewhere for a cause of bleeding. Do not get fixated on a single body cavity or single cause. Patients who are relatively stable in the trauma assessment area are candidates for truncal CT for definitive diagnosis and in particular require this to exclude occult injury. Abdominal examination is not sensitive in patients following major mechanism of injury or with multiple extremity or spine injuries. FAST is not sensitive for solid or hollow viscous injury. It simply identifies free fluid, which may indicate bleeding.

Neurologic Injury

The goal during the primary survey is simply to recognize life-threatening neurologic injury, particularly severe traumatic brain injury. Everything else can wait until time permits for a more thorough evaluation. Pupils and GCS should be inspected and estimated as part of the D in the ABCDE of initial assessment. Severe traumatic brain injury is characterized by GCS less than or equal to 8. Asymmetric pupils may indicate mass effect with impending transtentorial herniation. The presence of either mandates prompt neurosurgical consultation. The most effective initial management is to ensure that viable brain is preserved by maintaining oxygenation and perfusion. In these patients, vigorous resuscitation to avoid or correct hypotension is a priority. Resuscitation for patients with hemorrhagic shock should employ the institutions massive transfusion protocol. Mannitol 0.5–2 g/kg may be an effective temporizing maneuver in order to transiently minimize brain swelling and herniation. The same is true of temporary hyperventilation. In most cases normal $PaC0_2$ levels are desirable to avoid cerebral vasoconstriction, but in the case of impending herniation, this can be lifesaving.

CT of the head should be performed as soon as possible. Treatment of hemorrhage in order to maintain cerebral perfusion still takes precedence. Patients presenting with hemorrhagic shock still need to have the bleeding stopped first in most cases. Patients who respond to resuscitation and who in the judgment of the trauma team leader will maintain perfusion while undergoing CT may have an expedited CT performed first [33].

Traumatic brain injury (TBI) may be characterized as severe (GCS </=8), moderate (GCS 9–12), and mild (GCS 13–15) including concussion. Patients with moderate traumatic brain injury should undergo CT. Patients with mild TBI should be assessed in accordance with the Canadian CT head rule to determine whether CT vs. simple observation and follow-up is required. See Chap. 24 for an evidence-based discussion of imaging in stable patients. CT is required for patients with evidence of open, depressed, or basal skull fracture, persistent GCS < 15 beyond 2 h, age > 65 with loss of consciousness, amnesia or disorientation and/or vomiting two or more times. Consideration should be given to imaging those with dangerous mechanisms or amnesia for events >30 min [34, 35].

Musculoskeletal Trauma Including Spine

The priority is to identify long bone fractures in the primary survey. Another important goal is to do no further harm. Patients are initially exposed and log rolled, and extremities are inspected and rapidly palpated. During the secondary survey, all extremities and joints should be examined, including sensory, motor, and neurovascular examination.

Management of fractures is by immobilization and splinting. The entire spine, cervical, thoracic, and lumbar should be immobilized until spinal column injury has been ruled out. In most cases of major blunt mechanisms or penetrating injury with trajectory near the spine, X-rays are required. CT is not required for all injured patients but has proven invaluable for major blunt trauma patients, particularly those that also require truncal CT. If CT of the chest and abdomen/pelvis are not being performed, then plain radiographs should be obtained. For patients who did not have major mechanism, the Canadian C Spine rule [36] provides guidelines on when to request C-spine X-rays and when clinical exam is sufficient. If clinical exam is being relied upon, patients should be alert and cooperative, have no midline pain, and be able to actively rotate, extend, and flex the neck comfortably [37].

Patients who present with spinal cord or peripheral nerve injury should have initial findings carefully documented, and the injured part should be protected through immobilization. The primary management of these injuries in early trauma care is preservation of oxygenation, ventilation, and perfusion while taking care to do no further harm [38].

Management of extremity fracture is by splinting and immobilization. As already noted, direct compression of bleeding and/or application of a pelvic binder should already have been performed. Open fractures should receive antibiotic and tetanus prophylaxis as well as prompt orthopedic consultation. Dislocated joints should be recognized and reduced emergently, ideally in the trauma resuscitation area. If operative reduction is required, this should be performed emergently [39, 40].

Musculoskeletal injuries in major trauma patients are frequently not recognized during initial trauma assessment. A thorough secondary assessment when appropriate as well as routine performance and documentation of a tertiary survey within 24–36 h will identify these injuries. Reassessment, particularly when level of consciousness improves if initially compromised, will enhance detection rates and prevent morbidity due to delayed recognition.

Conclusions

An organized consistent approach by trauma practitioners and trauma teams will allow effective and safe management of the severely injured. Early identification and appreciation of shock is critical. Remember that in cases of hemorrhage, the priority is to stop the bleeding. As noted, rapid performance of an ABCDE assessment accompanied by a CXR, pelvic XR, and EFAST exam simplifies decision making in blunt trauma. Operative control or angio-embolization and musculoskeletal stabilization should occur immediately when required in trauma centers. In referring centers, well-organized trauma systems will focus on early identification, communication, and arrangement of transport.

Repeating the ABCs serially as well as point of care testing with ABGs initially and as required will allow all patients with evolving shock to be readily identified and appropriately resuscitated. Massive transfusion protocols and attention to avoidance of hypothermia, acidosis, and coagulopathy are keys to success [41].

Patients who have major mechanism and in whom major injury is obvious or suspected require thorough head to toe assessment, CT to rule out truncal and spine injury in the event of major mechanism, and liberal use of plain radiographs for all extremities and joints with pain or abnormal physical findings [42].

Trauma systems and teams are designed to ensure that resources and infrastructure are available to support safe care. Remember that trauma is not a solo sport; early engagement of the system and team saves lives [42–44]. Trauma care continues to evolve and adapt to changing technology, medical advances, and systems and team dynamics [45].

Key Points

- Organized trauma systems and trauma care significantly reduce injury death and morbidity.
- The ATLS® system provides a common global approach to trauma resuscitation. It allows teams and centers to speak a common language.
- The ABCDE principles of trauma resuscitation are equally valid when practiced sequentially or simultaneously by a trauma team.
- Trauma teams function optimally when members are prepared, leadership is clear, and communication is encouraged.
- Trauma resuscitation continues to improve with the adoption of balanced resuscitation, massive transfusion protocols, and adjuncts for rapid and definitive control of hemorrhage.

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14 Damage Control Resuscitation

Chad G. Ball

Introduction

Damage control is a Navy term defined as "the capacity of a ship to absorb damage and maintain mission integrity" [1]. Although the adaption of this term to the field of traumatology can be credited to Dr. Schwab and colleagues in 1993 [2], its dominant principles are more accurately rooted in Dr. Lucas and Ledgerwood's 1976 address to the American Association for the Surgery of Trauma [3]. More specifically, they described a small series of patients who underwent sponge-based packing of major liver injuries [3]. This concept was reiterated shortly thereafter by Calne [4], as well as Feliciano and Mattox [5] in 1979 and 1981, respectively. Despite these small series outlining the success of perihepatic packing, the visionary extrapolation of this principle to patients with multiple concurrent life-threatening injuries and major coagulopathy was not published until 1983 [6]. Harlan Stone retrospectively described 31 patients who developed major bleeding diatheses [6]. Of these, 17 patients underwent the modern damage control principles of arresting surgical hemorrhage and abbreviating the subsequent operative intervention. This led to the survival of 11 patients who were predicted to have a lethal coagulopathy.

The natural extension and further development of DCS has been damage control *resuscitation* (DCR). This concept includes DCS but also the early initiation of blood product transfusions and massive transfusion protocols, reduced crystalloid fluid administration, permissive hypotension in selected populations, and immediate hemorrhage control (whether operative or angiographic). In other words, DCR is a structured intervention that is mobile and can be delivered to a critically ill patient in any location (emergency department, interventional radiology suite, operating theater, and/or intensive care unit). Regardless of their destination, arresting hemorrhage, restoring blood volume, and correcting coagulopathy are ongoing.

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Massive Transfusion

Although the traditional definition of a massive transfusion is >10 units of red blood cells (RBC) in a 24-h period, this term has been modified with regard to both the amount of blood product and the time interval to better reflect true coagulation biochemistry [7, 8]. The 3 % and 8 % of civilian and military injuries, respectively, who require a massive transfusion are predictably associated with high mortality rates (27–51 %) [8]. Furthermore, the early coagulopathy of trauma is a well recognized entity that is present upon admission of over 25 % of injured patients with a base deficit greater than 6 [9]. Equally interesting, although coagulopathy was historically viewed as a by-product of resuscitation, hemodilution, and hypothermia, the bloody vicious cycle is now understood to be significantly more complex [10]. Tissue trauma, shock, hemodilution, hypothermia, acidemia, and inflammation all play key trigger roles in the acute coagulopathy of trauma-shock [10]. The improved understanding of interrelationships, and recognition of these six key initiators of coagulopathy, supports the modern use of massive transfusion protocols (MTPs) (Table 14.1).

A modern MTP aims to approximate delivery of a 1:1:1 ratio of RBC/fresh frozen plasma/platelets [10]. By addressing the early coagulopathy of trauma, MTPs have been shown to improve mortality in multiply injured populations [9, 11]. While the specific structure of MTPs varies slightly from center to center [12], they are all approximations of Sheldon's fresh whole blood resuscitation principles from 1975 [13]. Additional benefits of a formal MTP include earlier administration of blood products during resuscitations, improved blood banking efficiency, decreased total blood product utilization during a hospital stay, and significant economic savings [14]. It must also be noted, however, that

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Table 14.1 Massive transfusion protocol: package contents[a]

Package	PRBCs	Plasma	Platelets	Cryoprecipitate
Initiation	6 units (UD/TS)	6 units (UD)		
1 (0.5 h)	6 units (UD/TS)	6 units (UD)	1 apheresis[b]	
2 (1 h)	6 units (UD/TS)	6 units (TS)		20 units
3 (1.5 h)[c]	6 units (UD/TS)	6 units (TS)	1 apheresis[b]	
4 (2 h)	6 units (UD/TS)	6 units (TS)		10 units
5 (2.5 h)	6 units (UD/TS)	6 units (TS)	1 apheresis[b]	
6 (3 h)[d]	6 units (UD/TS)	6 units (TS)		10 units

PRBCs, packed red blood cells; UD, universal donor; TS, type specific
[a]PRBCs and plasma can be doubled to 12 units each per cycle by request
[b]1 apheresis unit of platelets is considered to equal 8–10 standard units
[c]Recombinant factor VIIa may be used at attending physician's discretion (dose: 3.6 mg, one repeat dose as needed in 30 min)
[d]If protocol is still active, alternate packages identical to packages 5 and 6 until protocol is terminated

reasonable scientific concern remains with regard to the apparent improvement in survival via MTPs [15]. The possibility of a strong survival bias based on survivorship (i.e., surviving long enough to receive the most RBC units) remains [15]. It should also be noted that although the potential benefits of MTPs have been widely publicized, numerous theoretical and observational complications have been linked to MTPs using retrospective registry data. These include, but are not limited to, potentially increased risks of acute lung injury (ALI), acute respiratory distress syndrome (ARDS), hypothermia, and other risks associated with the transfusion of any blood product [16–18]. Further study is clearly warranted and ongoing.

Another major benefit of an MTP is the avoidance of excess crystalloid fluid administration [19]. This reduction in crystalloid volume during the resuscitation period minimizes multiple associated side effects including reperfusion injury, increased leukocyte adhesion and inflammation, associated acidosis, resultant acute respiratory distress syndrome, systemic inflammatory response syndrome, and multi-organ failure [20–22]. On an anecdotal platform, excess crystalloid administration also remains an obstacle to obtaining early definitive fascial closure of the abdominal wall secondary to both visceral and abdominal wall edema.

An adjunct to massive transfusion that should be considered in severely injured trauma patients is tranexamic acid (TXA). One gram is given over 10 min followed by 1 g given over the next 8 h administered within 3 h of injury [23]. TXA has been associated with a lower mortality [23, 24]—most pronounced in the patients undergoing massive transfusion [24]. While the CRASH-2 trial found no adverse events related to TXA administration [23], the MATTERs study found a low, but significantly increased risk of pulmonary embolism (2.7 %) and deep venous thrombosis (2.4 %) [24]. Military data has demonstrated that in massively transfused patients, TXA was independently associated with survival and improved coagulopathy [24]. The mechanism of action is not well understood, but TXA is thought to not only stabilize clots but attenuate the inflammatory response. It is inexpensive and has been deemed relatively safe, and it seems that few patients are needed to treat to achieve a mortality benefit; thus, its use has been growing [24].

Initially, the use of recombinant factor VIIa, a procoagulant used in hemophilia, appeared promising for coagulopathic blunt trauma patients, reducing the amount of transfusions and the need for massive transfusion [25]. Unfortunately, it did not affect mortality or reach statistical significance for penetrating trauma [25]. Subsequently, its safety was questioned when data demonstrated an increased risk of thromboembolic events [26]. The CONTROL trial, a prospective, randomized, double-blinded, multicenter study attempting to determine the efficacy and safety of factor VIIa, was terminated early when it did not demonstrate mortality benefit with questionable enrollment [27]. Ultimately, future studies should be directed at answering these questions. In the interim, factor VIIa is reserved for patients in extremis, usually undergoing massive transfusion, with 200 μg/kg given at hour 0 and 100 μg/kg at post-injury hours 1 and 3.

Permissive Hypotension

Further mention of the concept of permissive hypotension is also prudent and must reference the original randomized controlled trial by Mattox and colleagues in 1994 [28]. More specifically, this trial successfully challenged the dogma of restoring a patient's blood pressure to physiologic levels in scenarios defined by ongoing hemorrhage. While this study was also heavily criticized due to the dominance of penetrating injuries and the proximity of patients to the trauma center, an updated prospective randomized trial has recently supported this initial observation in a multitude of injured patients [29]. This recent study noted that hypotensive resuscitation (MAP goal of 50 mmHg) is a safe strategy for injured patients that results in less overall blood product and intravenous fluid administration, decreased postoperative coagulopathy, and reduced early postoperative death [29]. Permissive hypotension is not appropriate for all populations, however, and should be avoided in the setting of potential concomitant head injuries and elderly population and if prolonged transport times or delays in definitive interventions are anticipated.

Damage Control Surgery and Its Indications

Once damage control surgery (DCS) was born, it was quickly marketed into other disciplines that included, but were not limited to, neck [30], vascular [31], orthopedic [32], thoracic [33], and military injuries [34]. The conceptual maturation of DCS has led to fundamental tenants that include (1) arresting surgical hemorrhage, (2) containment of gastrointestinal spillage, (3) surgical sponge insertion, and (4) temporary abdominal closure. This sequence is followed by immediate transfer to the intensive care unit with subsequent rewarming, correction of coagulopathy, and hemodynamic stabilization. Return to the operating theater is then pursued 6–48 h later for a planned reexploration that includes definitive repair and primary fascial closure if possible. It is clear that the DCS approach leads to improved survival for both blunt and penetrating injures in patients who are approaching physiologic exhaustion [35].

Despite the clear utility of DCS, its widespread propagation throughout the trauma community has led to a clear over-utilization of this technique. More specifically, multiply injured patients who are *not* approaching physiologic exhaustion are often exposed to the potential risks associated with open abdomens including infection, gastrointestinal fistula formation, and failure to achieve definitive closure with subsequent massive ventral hernias. As a result, the pertinent question remains: who needs DCS? The succinct response is "patients who are more likely to die from uncorrected shock states than from failure to complete organ repairs." Depending on the center, these "metabolic cripples" encompass 3–8 % of all *severely* injured patients (penetrating vs. blunt; military vs. civilian). In essence, they continue to suffer the sequelae of tissue shock that is manifest as *persistent* hypothermia, *persistent* metabolic acidosis, and nonmechanical (i.e., nonsurgical) bleeding. More specifically, DCS triggers include core temperature <35 °C, pH < 7.2, base deficit >15, and/or significant coagulopathies [7, 36–38]. It must be emphasized, however, that not even all patients with initial physiologic deficits as significant as these values mandate DCS. With rapid arrest of hemorrhage, as well as ongoing resuscitation, some patients will improve dramatically in all parameters on repeated intraoperative blood gas analyses. These patients stabilize and begin to recover. It should also be stated that patients with multiple intra-abdominal injuries are not always in metabolic failure.

Nonvascular persistent abdominal bleeding is most commonly related to the liver, spleen, pancreas, and/or kidney. Unlike the spleen and kidney, the liver and pancreas cannot generally be resected in a rapid on-demand basis. It should be noted however that prior to the removal of any kidney, palpation for a normal-sized contralateral kidney must be completed.

Technical details surrounding hepatic hemorrhage include leaving the falciform ligament intact to provide a medial wall against which to improve packing pressure (especially in blunt trauma). If hemorrhage continues, an early Pringle maneuver (clamping of the porta hepatis with a vascular clamp) is mandated as both a diagnostic and potentially therapeutic technique. If bleeding continues despite application of a Pringle clamp, a retrohepatic IVC or hepatic venous injury is likely. It should be noted that critically injured patients in physiologic extremis do not tolerate extended Pringle maneuvers to the same extent as patients with hepatic tumors undergoing elective hepatic resection (40 min upper limit). If the liver hemorrhage responds to packing but continues to hemorrhage when unpacking is completed, the patient should be repacked and transferred to the ICU with an open abdomen once damage control of concurrent injuries is complete. Covering the liver with a plastic layer of sterile x-ray cassette material avoids capsular trauma/oozing upon eventual unpacking. In the case of central hepatic gunshot wounds or deep central lacerations where access and exposure are difficult, ongoing hemorrhage can be stopped with balloon occlusion (see below). Return to the operating suite in patients with packed livers should occur in 72 h (assuming hypothermia, coagulopathy, and acidosis are corrected).

It should be noted that although the published history of hepatic trauma is littered with descriptions of various technical maneuvers ordered in a hierarchical scheme, very few are relevant in context of modern trauma care. More specifically, damage control packing of hepatic hemorrhage controls the vast majority of ongoing bleeding in critically ill patients.

Damage control pancreatic maneuvers are extremely limited and revolve around drainage of nearly all pancreatic injuries (either with a closed suction drain and an open abdomen or simply open abdomen alone). The dominant associated life-threatening scenario for peripancreatic injuries involves hemorrhage from the portal and superior mesenteric veins. Although these veins can be ligated, repairs are generally performed with 5-0 or 6-0 Prolene once control is obtained. Clamps above and below the injury are essential for visualization. Alternate damage control options include temporary intravascular shunts (TIVS) (described below) with a small chest tube conduit or ligation (assuming the hepatic artery is intact) [39]. Damage control maneuvers for the splenic vein are generally limited to bulk ligation.

Damage control technique for hollow viscous organs require ligation and subsequent exclusion of injured and/or leaking segments. This is typically performed using gastrointestinal staplers. The supplying mesenteries can be ligated in rapid fashion using clamps or vascular staplers. In the case of gastric division, the proximal stomach should be decompressed by a nasogastric tube. Small bowel and colon can be left in discontinuity for up to 48 h with minimal sequelae.

Vascular Damage Control Techniques

Although it is clear that arresting ongoing hemorrhage is the most crucial of damage control tenets, *vascular* damage control has been traditionally limited to vessel ligation. More recently, however, balloon catheter tamponade and temporary intravascular shunts (TIVS) have increased in popularity. The impressive utility of balloon catheters for tamponade of exsanguinating hemorrhage has a long history dating back more than 50 years [40]. Although this technique was originally described for esophageal varices [41], it was quickly extended to patients with traumatic vascular and solid organ injuries [42]. Since the initial treatment of an iliac arteriovenous lesion in 1960 [3], balloon catheters have also been used for cardiac [43], aortic [44], pelvic [45], neck (carotid, vertebral, and jugular) [46, 47], abdominal vascular [48], hepatic [49], subclavian [50], vertebral [40], and facial trauma [51]. While this technique was originally intended as an intraoperative endovascular tool [40], it has since been employed as an emergency room maneuver with the balloon being placed outside of the lumen of the injured vessel usually through the wound tract [52, 53].

Modern indications for this damage control technique are limited. This is primarily because routine methods for controlling hemorrhage, such as direct pressure, are typically successful. As a result, indications for catheter tamponade include (1) inaccessible (or difficult to access) major vascular injuries, (2) large cardiac injuries, and (3) deep solid organ parenchymal hemorrhage (liver and lung) [40, 43]. Of interest, the type of balloon catheter (Foley, Fogarty, Blakemore, or Penrose with red rubber Robinson), as well as the duration of indwelling, can vary significantly. In conclusion, balloon catheter tamponade is a valuable tool for damage control of exsanguinating hemorrhage when direct pressure fails or tourniquets are not applicable. It can be employed in multiple anatomic regions and for variable patterns of injury. Prolonged catheter placement for maintenance of hemostasis is particularly useful for central hepatic gunshot injuries [53].

Temporary intravascular shunts (TIVS) are intraluminal synthetic conduits that offer nonpermanent maintenance of arterial inflow and/or venous outflow [54]. As a result, they are frequently life and limb saving when patient physiology is hostile. By bridging a damaged vessel and maintaining blood flow, they address both acute hemorrhage and critical warm ischemia of distal organs and limbs. Although Eger and colleagues are commonly credited for pioneering the use of TIVS in modern vascular trauma [55], this technique was initially employed by Carrel in animal experiments [56]. The first documented use in humans occurred in 1915 when Tuffier employed paraffin-coated silver tubes to bridge injured arteries [57]. This technique evolved from glass to plastic conduits in World War II [58] and continues to vary both in structure and material among today's surgeons [59].

Modern indications for TIVS include (1) replantation, (2) open extremity fractures with concurrent extensive soft tissue loss and arterial injury (Gustilo IIIC), (3) peripheral vascular damage control, (4) truncal vascular damage control, and (5) temporary stabilization prior to transport [54, 60]. While the understanding of TIVS use for military and civilian settings is increasing [59], the optimal shunt material, dwell time, and anticoagulation requirements remain poorly studied. It can be noted, however, that TIVS are remarkably durable and rarely clot unless they (1) are too small (diameter), (2) kink because of inappropriate length, and/or (3) are placed in an extremity without appropriate (or shunted) venous outflow (venous hypertension leads to arterial thrombosis) [60].

Despite the penetrating mechanism dogma associated with TIVS over the past 40 years, the majority (64 %) of TIVS in a large national database (National Trauma Data Bank—NTDB) were used in patients injured via a blunt mechanism [61]. Although the kinetic force of an motor vehicle crash (MVC) or MVC-pedestrian collision can be tremendous, TIVS is often discussed in the context of extremity damage control for gunshot wounds in patients with hostile physiology [61]. This NTDB analysis however indicated that most extremity TIVS are actually placed for blunt vascular trauma associated with extensive orthopedic and/or soft tissue injuries (74 %). They are also most often used as a temporizing maneuver to provide distal flow to a limb while orthopedic injuries are assessed and fixated. The use of TIVS for this scenario is well recognized and documented to significantly reduce the rate of amputation. In the patients who did not undergo TIVS for fractures and soft tissue defects, it appears that shunting was employed as an extremity damage control technique in those who presented with hemodynamic instability and severe base deficits (26 %) [61]. These patients displayed a much lower level of subsequent amputation when compared to cases of blunt trauma with concurrent fractures and soft tissue trauma. In addition to using TIVS in blunt-injured patients, the NTDB also indicates that this technique is being performed relatively uncommonly across a wide range of hospitals [61]. Of 111 trauma centers employing TIVS, only six used five or more shunts throughout the study period. Additionally, only three centers employed more than ten shunts. TIVS appear to be useful in any scenario with a major vascular injury and hostile patient physiology. This includes cases of blunt MVC trauma with concurrent severe extremity fractures and/or soft tissue injuries. In spite of their simplicity, however, they are underutilized.

Abdominal Compartment Syndrome

Abdominal compartment syndrome (ACS) is defined as sustained intra-abdominal pressure greater than 20 mmHg that is associated with new organ dysfunction/failure [62–67]. ACS differs from intra-abdominal hypertension (IAH) which is a graded (I–IV) and sustained pathological elevation greater than 12 mmHg. Symptoms of ACS are extensive and impact every major system within the human body. These include, but are not limited to, cardiovascular (hypotension), renal (acute kidney injury), and respiratory (failure) elements. It is interesting to note that many of the dominant risk factors for developing ACS mirror the physiologic triggers for engaging in DCS/DCR [62, 63]. This observation supports these physiologic variables (pH, base deficit, core temperature) as clear markers for the absolute "sickest of the sick." Closing abdomens in patients manifesting physiologic extremis often leads to ACS, as first demonstrated by Morris Jr. and colleagues in 1993 [64]. With closure, these authors described severe abdominal distension in concert with raised peak airway pressures, CO_2 retention, and oliguria [64]. Their observed 63 % mortality rate associated with reperfusion injury after unpacking was also dramatic and currently emphasizes the importance of "recurrent" or "tertiary" ACS [65]. While the incidence of primary ACS has decreased dramatically over the past decade [62], continued vigilance is crucial to guard against secondary and recurrent ACS. Despite the increased understanding surrounding this anatomic and physiologic complication, however, it is clear that the actual practice of clinicians requires more education with regard to both monitoring and treating ACS [66]. This reality has led to a recent evidence-based update of both definitions of primary, secondary, and recurrent ACS and an expert society's therapeutic recommendations [67]. More specifically, in addition to multiple "suggestions," the World Congress of the Abdominal Compartment Syndrome (WCACS) strongly recommends the following: (1) measuring IAP when any known risk factor for IAH/ACS is present in a critically ill or injured patient using a trans-bladder technique (GRADE 1C), (2) utilizing protocolized monitoring and management of IAP (GRADE 1C), (3) engaging in a decompressive laparotomy for cases of overt ACS (GRADE 1D), (4) attempting to ensure the-same-hospital-stay abdominal fascial closure (GRADE 1D), and (5) utilizing negative suction therapy in patients with open abdominal cavities (GRADE 1D) [67]. It should also be noted that some patients may adequately respond to decompression (nasogastric, colonic, intraperitoneal (i.e., ascites)) and/or increased sedation/paralysis as primary therapeutic maneuvers. Failure to resolve ACS with these medical therapies, however, should lead to rapid surgical decompression. Measuring intra-abdominal pressures can be easily performed at the bedside with a three-way Foley catheter, pressure transducer, and intravenous tubing.

Open Abdominal Management

The concept of delaying abdominal wall closure is credited to Dr. Stone at Grady Memorial Hospital in 1981 [68]. Among 167 patients, mortality approximated 85 % in those whose abdomens were closed under tension, compared to only 22 % who underwent delayed fascial closure. This truly remarkable report altered the DCS landscape dramatically. Unfortunately, the open abdomen is also responsible for significant short-term (fluid and protein loss, sepsis, intestinal fistulae, nursing care challenges, economic costs) and long-term (chronic physical discomfort, physique embarrassment, delayed return to work, poor quality of life) morbidity [69–72]. Although multiple techniques are described for managing the open abdomen (Table 14.2), it is clear that intestinal coverage (via endogenous abdominal wall or skin or split-thickness skin graft) must be achieved as soon as possible to limit subsequent fistulae. It is also evident that regardless of technique, severely injured patients more commonly achieve fascial closure during their initial hospital stay than their non-trauma, acute care surgery counterparts. If closed too early, however, ACS, fascial dehiscence, necrotizing fasciitis, and ventilation challenges are notable complications.

Despite the poor methodology inherent in the open abdomen literature (i.e., mixed patient cohorts, lack of complete inclusion, ignorance of non-survivors, variable individual surgeon effort and interest), it is evident that negative suction dressings have improved closure rates and reduced complications such as intestinal fistulae. Whether home grown [73] or commercially derived [74], these technologies have advanced to the point where they have now become commonplace. The two dominant principles when utilizing negative suction therapy remain: (1) maintenance of the peritoneal/abdominal domain and (2) continuous and

Table 14.2 Open abdomen coverage techniques

Skin only	Polypropylene mesh
Towel clip	Polyglycolic/polylactic acid mesh
Silastic sheet	Polytetrafluoroethylene mesh
Bogota bag	Parachute silk
3 l genitourinary bag	Hydrogel/Aquacel
Steri-Drape/x-ray cassette	Ioban
Zippers	Vacuum pack
Slide fasteners	Abdominal wound VAC
Velcro analogue/Wittmann	Bioprosthetics

progressive tension on the midline abdominal wall. These goals are achieved by insertion of a plastic barrier deep into the paracolic gutters (maximally lateral to prevent adhesions between the colon and abdominal wall) and generation of midline abdominal wall tension using non-fascial retention sutures or commercial systems. It should also be noted that intra-abdominal pressures often exceed “normal” levels (>20 mmHg) immediately after progressive increases in tension at the midline during repeat laparotomy and attempted closure. This typically abates over the subsequent few hours and is considered acceptable in the absence of end-organ ischemia (decreased urine output, increased airway pressures). As a result, it is considered fundamentally different from the acute phase of ACS. If the intra-abdominal pressure does not normalize, however, the abdomen must be reopened to prevent recurrent ACS.

An individual patient with an open abdomen will either continue to improve, mobilize fluid, and allow gradual abdominal closure via repeat laparotomies or continue to be challenged with sepsis and multi-organ failure, will not mobilize fluid, and will eventually require skin graft coverage. Entero-atmospheric fistulae must also be prevented at all costs. This morbidity not only complicates short-term management but also eventual abdominal wall reconstruction (component separation, modified component separation). If present, these fistulae are best intubated by soft rubber catheters placed within the sponge material of negative pressure suction dressing [75]. Over time, this will allow the clinician to develop a granulation plate around the fistulae appropriate for a skin graft (i.e., conversion into a stoma).

A detailed discussion of the tiered algorithm for abdominal wall reconstruction, as well as the indications for occasional use of biologic materials, is beyond the goals of this review. Clearly, the appropriate timing of reconstruction (8–12 months) is crucial to the success of the repair (adhesions vs. rectus muscle lateral retraction). Extensive experience in reconstructive techniques is crucial to ensure acceptable outcomes. These principles include, but are not limited to, timing, sequencing (stoma reversal, fistula closure), ensuring adequate skin coverage, sparing of periumbilical perforators, minimally invasive lateral releases, and management of wound complications.

In conclusion, DCR includes early blood product transfusion, arrest of ongoing hemorrhage, and restoration of patient blood volume and physiologic/hematologic status. As a result, it recognizes and addresses the early coagulopathy of trauma, avoids massive crystalloid resuscitation, and leaves the peritoneal cavity open when a patient approaches physiologic exhaustion without improvement. DCS vascular techniques include balloon tamponade, as well as temporary intravascular shunts.

Key Points

- Damage control resuscitation incorporates principles of early blood product transfusion, minimization of crystalloid administration, permissive hypotension, abbreviated operative interventions, and sustained critical care with early reoperation.
- Vascular damage control techniques include the placement of balloon tamponade and temporary intravascular shunts.
- Successful closure of the fascia in open abdomens during the same hospital stay requires perseverance by the surgeon to apply progressive midline tension and maintain abdominal domain.

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Damage Control: From Principles to Practice

15

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Introduction

Trauma patients present with unique physiology and anatomy that challenge the trauma team. Multiple cavities can be involved, and prioritizing operative interventions must be undertaken with little patient or clinical data. Further complicating the clinical picture is the delayed presentation of the trauma patient whether due to environmental, transport, or patient factors. This can lead to physiologic derangements from uncontrolled bleeding and/or contamination. Historically, the surgeon would complete the operation, including all bowel and vascular anastomoses, and close the abdomen. Complications such as abdominal compartment syndrome and later multisystem organ failure would ensue [1, 2]. As discussed in the preceding chapter, this lead surgeons to challenge the traditional approach by aborting the operation early and creating a staged approach in a concept termed "damage control" (Fig. 15.1). First described in 1983 [3], damage control demonstrated improved outcomes in 1993 [4]. Subsequently, improvements in certain stages have been described, and recognition that many physiologic challenges begin the moment injury occurs has led to implementing changes in the prehospital setting [5, 6]. Initially, damage control surgery was applied to intra-abdominal injuries, but now has been expanded to include thoracic, vascular, and extremity injuries [7, 8]. The military uses damage control across theaters—temporizing on the front lines, resuscitating and stabilizing at a forward operating base, and then transporting to a higher level of care at a well-established military base, sometimes in another country or even continent [9–11]. This chapter will build on the principles discussed in Chap. 14 and highlight their application to real-life scenarios.

Indications for Damage Control Surgery

The goal of damage control surgery is to recognize patients who are physiologically deranged, need second explorations, or are at risk for complications if the traditional approach with closure is undertaken. The lethal triad of hypothermia, coagulopathy, and acidosis appears as the patient reaches physiologic exhaustion, so waiting for the triad to develop and then undertaking damage control defeats the purpose of damage control. Bleeding and contamination are controlled in the first operation. Then, the patient is taken to the intensive care unit (ICU) for resuscitation, allowing time to recapture the patient's physiology.

Identification of patients who benefit from damage control surgery is an art that requires experience and communication. Emergency medical services (EMS) can communicate valuable information prior to patient arrival, such as prehospital hypotension, hypothermia, blood loss, and ongoing hemorrhage that can trigger the trauma team to entertain damage control. Even a single episode of prehospital hypotension that resolves with resuscitation can be indicative of a severely injured patient with little reserve for a lengthy operation [12]. Intraoperatively, hypothermia less than 36 °C, an acidosis less than 7.25 or base deficit greater than 8, clinical coagulopathy or based on laboratory values with an international normalized ratio (INR) greater than 1.5 or fibrinogen <200 mg/dl (<2 g/l) are indications for damage control. Constant and effective communication with anesthesia is necessary to ensure frequent monitoring, guide resuscitation,

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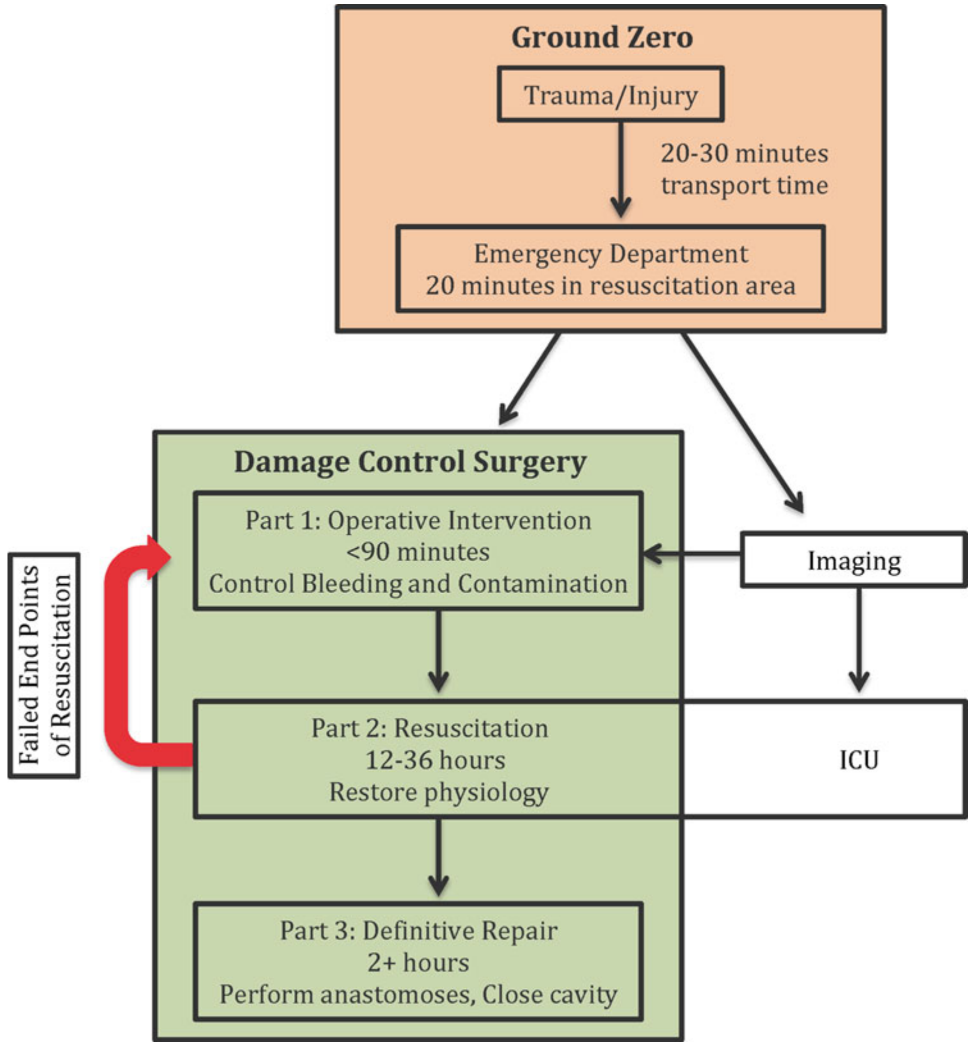

Fig. 15.1 Damage control sequence. Part 2 occurs in the ICU. Parts 1 and 2 may be repeated multiple times over several days to a week prior to Part 3 definitive repair

and communicate the decision to abort the operation and rapidly proceed to the ICU.

Patients with multiple cavity injuries are ideal candidates for damage control. Ongoing bleeding can hasten physiologic exhaustion, so hemorrhage control across cavities must be expeditiously treated with no opportunity for definitive repair. For example, a patient with a thoracoabdominal injury or multiple stab wounds may need both the abdomen and mediastinum or thorax explored, and the surgeon must make a judgment about which cavity is the primary source of bleeding or life-threatening injury. Once bleeding is controlled in one cavity, the surgeon must rapidly examine the next. Other situations that lend themselves to damage control are those where endovascular techniques may achieve hemorrhage control more effectively such as severe liver or pelvic bleeding. While waiting for the endovascular team to arrive, the surgeon may explore the abdomen and pack the liver or pelvis and even isolate and temporarily occlude the porta hepatis or internal iliac arteries. Once the endovascular team is available, the surgeon and radiologists can work together to combine operative and endovascular interventions to stop bleeding. Patient selection also plays a role; the elderly, those with more comorbidities, and pediatric patients have less reserve, and thus, the team should have a lower threshold for damage control. Ultimately, the earlier the decision is made to undertake damage control, the better chance of salvaging the patient.

Ground Zero: Scene to Emergency Department

Advanced Trauma Life Support (ATLS) is the backbone of prehospital treatment. Transport to a definitive trauma center without delay is the primary goal of ATLS and prehospital care with a goal of less than 30 min from call initiation to arrival at the trauma center. An airway must be established if a patient cannot protect his own. Needle decompression or tube thoracostomy may be performed for hypoxia and loss of

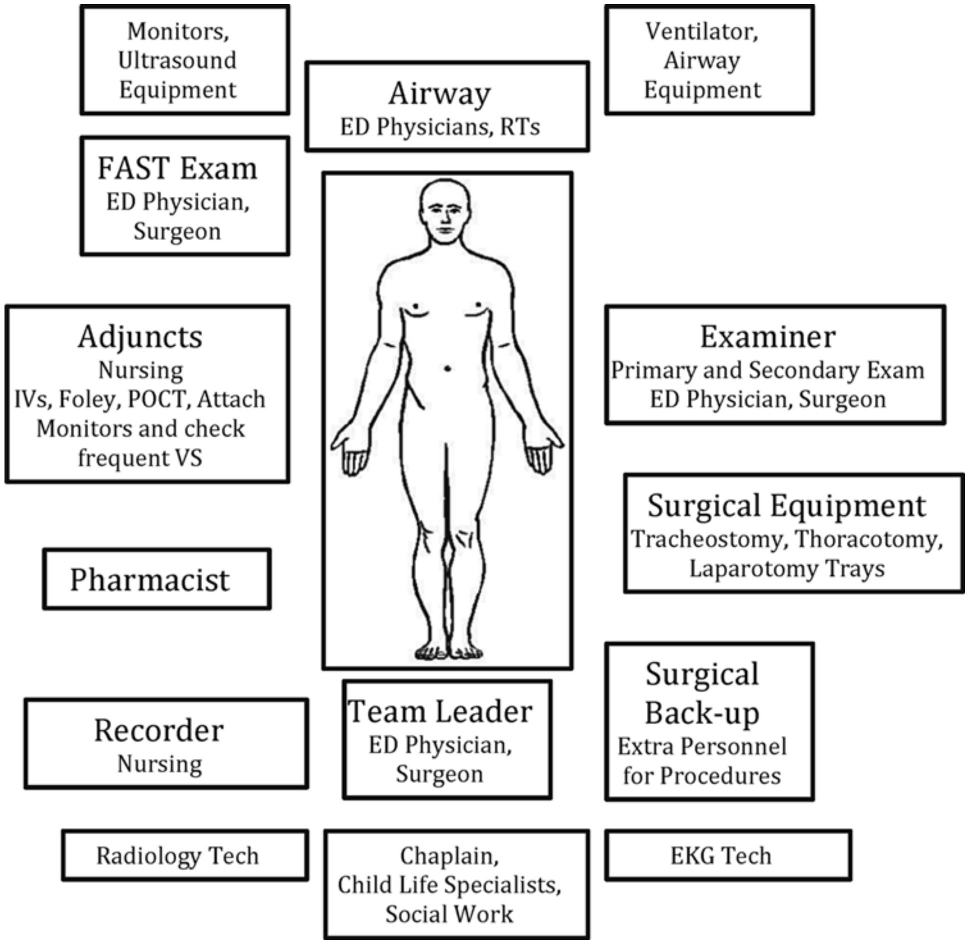

Fig. 15.2 Arrangement of Emergency Department resuscitation area conducive to effective communication. Note that the Recorder is adjacent to the Team Leader to read back information. Examiner should be on patient's left side to facilitate Emergency Department (ED) thoracotomy and other surgical procedures if necessary. Supply carts and medication dispensers/storage should be in close proximity if not in the same room along the walls. RT = Respiratory Therapist, POCT = Point of Care Testing, VS = Vital Signs, EKG = Electrocardiogram

breath sounds. Large-bore IVs should be placed, and resuscitation begun with isotonic crystalloid. Hemorrhage can be controlled with tourniquets or digital pressure. Fractures can be splinted to provide stability and decrease ongoing bleeding. Previously, 2 l of isotonic crystalloid were given followed by either more crystalloid or blood products if available to achieve a desired response in vital signs. As discussed in Chap. 14, under certain circumstances, a systolic blood pressure of 80–90 mmHg may be more ideal until hemorrhage is controlled [13]. This practice of "permissive hypotension" primarily applies to penetrating trauma with a short anticipated transport time to definitive care and only in the absence of head injuries and significant patient comorbidity.

Frequent, effective communication is imperative between the prehospital and emergency department teams. Updates on vital signs and physical findings allow emergency department personnel to mobilize resources. Necessary equipment can be gathered and procedure trays opened. Radiology technicians can be at the bedside waiting with portable X-rays and can expedite any other radiological interventions such as computed tomography (CT). The blood bank can be notified if a massive transfusion is planned in order to begin thawing products. Most importantly, roles during the triage are assigned and performed in an organized manner. Mobilization of the team prior to patient arrival decreases evaluation time and eliminates delay to imaging or the operating room.

The patient should ideally spend as little time as possible—certainly no more than 20 min—in the emergency department resuscitation/trauma area including procedures and adjuncts (Fig. 15.2). The trauma team must decipher what the life-threatening injuries are which determines the next stage of damage control. In trauma patients with blunt mechanisms, multiple cavities may be involved, and the sources of hemorrhage difficult to identify as they may not be visible. Penetrating traumas are much easier to triage, given the external wound. It is important to determine trajectory; the external wound may appear to lie within a single cavity, but trauma may involve multiple cavities. It is important to place a marker such as a paperclip or electrocardiogram (EKG) lead on the external wound prior to imaging in order to approximate trajectory.

The majority of trauma patients who are hypotensive are in hemorrhagic shock. A patient may exsanguinate externally or internally (thorax, abdomen, pelvis, retroperitoneum, soft tissues). If life-threatening bleeding is ongoing in one of the above mentioned cavities and/or the patient unstable, the surgeon should proceed rapidly to the operating room. Should a patient arrest just prior to arrival or in the resuscitation bay, an emergent resuscitative thoracotomy may be performed to release a cardiac tamponade and/or occlude the aorta in order to maintain perfusion to the heart and brain. Since endovascular technology has further evolved, the use of resuscitative endovascular balloon occlusion of the aorta (REBOA) in trauma is being revisited [14]. While it cannot relieve a cardiac tamponade, REBOA can be used in blunt or penetrating trauma prior to arrest to manage non-compressible hemorrhage at multiple levels of the aorta without the morbidity of a large chest wound [15]. The femoral artery may be accessed percutaneously or by cut down, and balloon placement does not require fluoroscopy [14, 15].

Depending on patient stability and resource availability, the team may elect to obtain a CT to gain further information. If a liver injury or pelvic fracture with bleeding is found, the team may proceed to a hybrid operating and endovascular room (when available) to control hemorrhage operatively while mobilizing the endovascular team.

Again, effective communication is of utmost importance in efficient patient flow. The CT technologist should be notified that the patient will be arriving imminently. The ordered scans should be discussed and clarified. It helps the technologist and radiologist reading the imaging to know the history (including mechanism) and physical exam findings as well as the suspected injuries as they may recommend arterial and venous phased scans, thinner slices through worrisome areas, or additional scans while the patient is still on the table. If there is a possibility the patient may be proceeding to the operating room, notifying the operating room team at the earliest opportunity is ideal. Some centers place the operating room (OR) staff on standby when the trauma team is activated in the emergency department. While a trauma-ready operating room is always available at a Level 1 center, the lights can be turned on, the room and bed warmed, and the nurse, scrub technician, and anesthesia team mobilized to prepare for a case. A trauma cart with basic supplies (shunts, staplers, tubes, drains, vacuum dressings) and various trays (vascular, thoracotomy, laparotomy) as well as a trauma suture tree should already be available in the room or just outside. Finally, the massive transfusion protocol should be implemented as soon as deemed necessary to ensure products are available as soon as possible whether it be in the ICU or operating room.

Damage Control Part 1: Operative Intervention

There are two goals in damage control Part 1: control of bleeding and contamination. Upon arrival to the room, the surgeon may give the team a brief history, interventions undertaken thus far, lines and tubes in place or needed, and the overall plan for the operation. It can be extremely helpful if anticipated problems are vocalized, so that anesthesia staff can prepare for the resuscitation and have rapid transfusers and cell savers available, while the OR staff can ready an abundant supply of sponges, basins, and adequate suction. In extreme situations, intubation may be occurring while prepping and draping the patient. In some instances, time will only permit splash prep.

Positioning the patient is dependent on which cavities or extremities need to be explored as previously determined in the emergency department. Any extremity may be prepped, draped, and included in the operative field. If a vascular injury is suspected, both legs from the inguinal ligament to knees should be prepped in case vein graft is needed. Generally, the trauma patient is supine with both arms abducted at 90° and prepped from chin to knees and laterally to the bed. If a combined thoracotomy and laparotomy is entertained and the hemithorax previously determined, a modified taxi cab hailing position is ideal. The patient is primarily supine, but on the ipsilateral side of the thorax to be entered, the chest wall is rotated medially about 30° to the coronal plane and supported with a roll. The ipsilateral arm is abducted at 90° and elbow flexed at 30°.

Once a cavity is opened, hematoma and blood should be evacuated (usually manually) and the cavity packed with lap sponges. If exsanguination is temporized, anesthesia should be allowed to aggressively resuscitate the patient until bleeding restarts or until the systolic blood pressure is 80–90 mmHg. All injuries must be fully exposed to localize hemorrhage and contamination. Bleeding organs on a pedicle (spleen, kidney) should ideally be sacrificed. Liver and lung resections are non-anatomical and usually performed with staplers. Finger occlusion of a pedicle and the Pringle maneuver for the liver or twisting the lung at its hilum are fast techniques to control significant bleeding. Various maneuvers (Kocher, Mattox, Cattell-Braasch) expose the retroperitoneum. Most vessels may be ligated. If a vessel supplies an end organ or extremity, the vessel should be shunted [16–19]. However, in life-threatening situations, even the inferior vena cava may be ligated at its bifurcation. Visceral contamination is controlled by stapling and removing the injured segment of bowel or simply whip stitching the injury closed. If a segment is removed, the patient is left in discontinuity due to time and the need for a second look given the possibility of further necrosis. A temporary abdominal, chest, or extremity dressing is placed, allowing for rapid reentry or examination while preserving the fascia and skin for definitive closure. These may be manufactured or homemade with negative pressure applied. Incorrect counts are common due to the emergent nature of the operation. While attempts are made to count the number of sponges and instruments left in a packed, open cavity, the count should never delay placement of a temporary dressing and transport to the ICU.

Again, communication with bed control to ensure an ICU bed is available and with the ICU nurses and physicians eases the transition to the next stage of damage control. It may take time to move another patient out of an ICU room, clean the room, and bring the hospital bed to the operating room. Report can be called about 20–30 min prior to leaving the operating room which allows the ICU staff time to set up suctioning, warming, and massive transfusion equipment, gather pumps, tubing and supplies, and prepare for the patient as well as notify respiratory therapy to bring a ventilator to the ICU room.

Damage Control Part 2: Resuscitation

The goal of Part 2 is to continue aggressive resuscitation in a rapid fashion in order to correct the physiologic derangements. Upon arrival to the ICU, the surgical team should communicate the brief history, interventions, the definitive plan, and any specific concerns. A full laboratory panel should be sent upon arrival to the ICU including a complete blood count (CBC) with differential, complete metabolic panel (CMP) with all electrolytes, creatine kinase (CK), lactic acid (LA), arterial blood gas (ABG), and coagulation panel including fibrinogen and repeated at minimum every 4–6 h (up to every 1–2 h in certain circumstances) to guide resuscitation and organ perfusion endpoints. Serial troponins and electrocardiograms may also be included. Core temperature should be monitored and rewarming measures such as blankets and warmed fluids used because hypothermia can inactivate the clotting cascade and impede the body's ability to coagulate blood.

While the resuscitation ratio is debated, a 1:1 or 1:2 ratio of packed red blood cells (pRBCs) to fresh frozen plasma (FFP) is the current recommendation. The goal of resuscitation is to achieve a hemoglobin ≥ 7 g/dL (>70 g/l) (>9 g/dl, 90 g/l in an actively bleeding patient), INR <1.5, maintain platelets >100,000, and cryoprecipitate may need to be given if the fibrinogen is <200 mg/dl (<2 g/l). If these goals are met, isotonic crystalloid may be used, but be mindful that normal saline may lead to a non-anion gas metabolic acidosis, worsening coagulopathy.

There is no single resuscitative endpoint. Clinically, urine output may be measured and stabilization in vital signs with titration of pressors off is indicative that end-organ perfusion is being achieved. The characteristic of the output from the temporary vacuum dressing and the amounts from the drains and tubes should be monitored. Ultrasound can help guide resuscitation, as intravascular volume can be based on inferior vena cava (IVC) collapsibility and cardiac contraction. This will be discussed further in Chap. 22. Corrections of the coagulopathy, hypothermia, and acidosis are guidance parameters.

Another important role of the ICU provider is to perform a thorough tertiary survey including physical examination and review of pertinent imaging and blood work to ensure that no injuries or wounds have been missed. Once resuscitation endpoints are met ideally within 24–36 h, the patient is returned to the operating room for a second look, or Part 3—definitive repair. If at any point during Part 2 the acidosis or coagulopathy is not correcting or was trending in the correct direction, but then regresses, or if there is clinical evidence of ongoing, rapid hemorrhage, the patient should be immediately returned to the operating room as this is indicative of a missed injury or ongoing, uncontrolled bleeding.

Finally, complications of resuscitation can arise. Acute respiratory distress syndrome (ARDS) and transfusion-related acute lung injury (TRALI) can result from aggressive resuscitation and blood product administration. One should, however, consider other differential causes for persistent hypoxemia, i.e., abdominal compartment syndrome. In the event of persistent hypoxemia, lung protective strategies such as ARDSNet ventilation should be implemented.

Compartment syndrome may develop in the abdomen even with a temporary dressing in place. It should be suspected if cardiac return is low, the IVC is collapsed on ultrasound, and the urine output decreases when previously appropriate or in the event of persistent hypoxia or hypercarbia with climbing ventilation pressures. Bladder pressures should be measured frequently or even continuously. If pressures remain high, the dressing may need to be modified, loosened, or reapplied.

For extremities, a Stryker needle can be used to objectively quantify the pressure; rapid, significant increases in compartment pressures, a measured compartment pressure >30 mmHg, or <30 mmHg difference in the diastolic blood pressure and measured compartment pressure should prompt fasciotomies.

Damage Control Part 3: Definitive Repair

Once the patient is resuscitated as defined by meeting end-organ and hemodynamic endpoints, the patient is returned to the operating room for definitive repair. The temporary dressing and all packs are removed. The cavity should be thoroughly explored. If at any point the patient becomes hemodynamically unstable or physiologically deranged as in Part 1, begins re-bleeding, or demonstrates they are unable to undergo a lengthy operation, the temporary dressing may be reapplied and the patient returned to the ICU for further resuscitation. Definitive repair entails restoring bowel continuity, tissue debridement, and vascular grafts and anastomoses. Prior to closing the abdomen, an X-ray should be obtained and confirmed with radiology that no foreign bodies remain in the cavity. If multiple cavities are left open in Part 1, all cavities may be closed in Part 3 or only one and Part 3 repeated for each cavity.

Damage Control Strategy Under Special Circumstances

The following represents specific treatment strategies for unique conditions. The ultimate goal of each strategy is to implement the damage control concept early in care, combat the lethal triad, and transport victims safely for definitive management.

Blast Injuries

Blast injuries are challenging as patients can suffer from both penetrating and blunt mechanisms. Treatment goals remain the same, and ABCs initially assessed. The provider should not become distracted by the often unsightly injury, but rather focus on treatment according to protocol and standard practice. Cricothyroidotomy may be necessary with a blast to the face. Damage control with the blast-injured patients is done in large part by controlling hemorrhage. Hemorrhage sites are either anatomically compressible (e.g., extremity, or axillary/groin vascular injuries) or completely non-compressible (e.g., truncal injuries). Patients with non-compressible hemorrhage sources receive the highest priority for immediate transport to a hospital. Compressible hemorrhage sites are amenable to direct digital pressure or tourniquet control, which can be instituted by first responders. Control of bleeding with proximally arterial compression is not advised as it does not address venous hemorrhage. Using large stacks of gauze or additional dressings in lieu of manual compression should be avoided, as this technique dissipates the pressure applied directly to the bleeding site and may delay identification of ongoing bleeding [20].

While use of tourniquets has been controversial in the damage control situation, multiple reports in the literature of tourniquet use have defined their advantages [21–26]. These include improved hemorrhage control upon patient arrival, decreased incidence of shock in those casualties treated with tourniquets, improved survival, and acceptably low tourniquet-related complications. Tourniquets should be applied to exsanguinating extremities as soon as possible in damage control situations. It is generally recommended that restoration of arterial blood supply must be completed within 6 h from placement of the tourniquet [20]. Prior to patient arrival, it is helpful for the emergency department personnel to know if a tourniquet was placed and when, the characteristic of bleeding (dark non-pulsatile versus bright red, pulsatile), and a description of the injuries. When giving report at patient arrival, the transport team should include the time of injury and approximate amount of blood loss at the scene.

If the patient's bleeding is controlled upon arrival, the primary and secondary surveys should be rapidly conducted in the usual fashion, and the four remaining cavities assessed for hemorrhage with the usual adjuncts. Blast injuries can create penetrating wounds from shrapnel, but can throw a patient with great force, causing blunt injuries as well. This is the ideal situation for damage control. When proceeding to the operating room, the staff should be told to obtain a sterile pneumatic tourniquet and prepare for abdominal and extremity exploration and temporary dressings. If extremity hemorrhage is controlled with a tourniquet and the patient's FAST is positive and if two teams are available, both the extremity and abdomen may be explored concurrently; in the case of a single operative team, however, one should begin with abdominal exploration if the extremity hemorrhage is controlled with a tourniquet. All exsanguination must be expeditiously stopped.

Should blood supply to an extremity be compromised for greater than 4–6 h, or if there is already concern for compartment syndrome, fasciotomies should be undertaken in Part 1. If fasciotomies are not performed, it should be relayed to the ICU team to clinically assess the compartments hourly.

Burns

Many providers hesitate to treat burn patients, as they are not comfortable and confident. The same ATLS principles apply. Burn patients, too, can suffer from multiple mechanisms as an explosion may cause a burn, produce shrapnel and penetrating injuries, and throw the patient causing a blunt mechanism. The standard primary and secondary survey, as with any other trauma patient, should be followed.

Burn care commences at the scene. As in all circumstances, personal protection is paramount. The provider must ensure that the scene is safe. Personal protection equipment should be applied. Patients should be immediately placed on 100 % O_2 as the adequacy of the airway is evaluated. The provider should pay particular attention to signs of impending airway edema or collapse, such as hoarseness. Patients will often have singed nasal and facial hair or eyebrows. While these findings are important to note and represent a significant injury to the face, they are not specific for airway compromise. Hoarseness, on the other hand, is representative of vocal cord injury or edema and should prompt rapid intubation in the setting of significant mechanism.

After an airway is established, it is important to check the adequacy of ventilation by watching the chest rise and fall. Patients may have circumferential third-degree burns which ultimately limit the expansion of the chest. In some circumstances and under the direction of a physician, sharp release of the constricting skin may be necessary to allow for adequate chest expansion [27].

The American Burn Association (ABA) recommends that if prehospital personnel are unable to establish IV access, hospital transport should not be delayed. Intraosseous access should be considered to expedite timeliness of resuscitation and transport. IVs must be frequently assessed because aggressive resuscitation can lead to rapid edema, IV dislodgement, and subsequent subcutaneous infiltration.

The patient should be completely exposed. A clean dry dressing should be applied. The patient should be wrapped in warm blankets to prevent heat loss. The trauma resuscitation area should be warmed above 80 °F (26 °C). No attempt should be made to cool the patient to counter the burning process; this may be a potentially lethal intervention. Patients have lost the barrier needed for thermoregulation, and despite the appearance of burned skin, patients are often hypothermic [27, 28].

Burn patients at the extremes of age, with significant or multiple comorbidities, obvious second- and third-degree burns that are >10 %, inhalational injury, or burns to sensitive areas such as the face, hands, feet, or genitalia, should be directly transported to a burn center if possible. Again, communication between the care components and damage control parts is imperative. A good report from the transport crew includes if the burn occurred in a closed space (potential inhalation injury), if an explosion occurred (multiple mechanisms), if the patient experienced a loss of consciousness (carbon monoxide poisoning or anoxic brain injury), and most importantly, the time of the injury to calculate resuscitation recommendations. The airway and face should be described as intubation may need to rapidly be undertaken and may be extremely difficult due to edema. Knowledge prior to the patient's arrival allows for extra supplies to be gathered including a tracheostomy tray and wide range of endotracheal tube sizes. A Rule of Nines figure (used to calculate burned body surface area) should be posted in the emergency department and should be reviewed prior to patient arrival. A paper copy to go in the patient's chart should be precisely completed.

Resuscitation in burn patients is based primarily on urine output (0.5 cm^3/kg/h in adults, 1 cm^3/kg/h in children <30 kg), so an indwelling bladder catheter is required. The Parkland formula—4 cm^3/kg/percentage of second- and third-degree burns of Lactated Ringer's with half given in the first 8 h from the time of injury and the remaining in the following 16 h—is a guideline of how to initiate resuscitation and may be adjusted to achieve urine output goals. It is imperative that all team members monitor end-organ perfusion, recognize the goals of resuscitation, and communicate about changes needed to achieve the goals.

If a burn patient is found to have a concomitant life-threatening injury such as intra-abdominal hemorrhage, the patient should be taken to the operating room, explored, and undergo the damage control sequence as any other trauma patient would. The goals of resuscitation must be clarified with anesthesia, because these patients require a significant amount of fluid and run the risk of leaving the operating room under-resuscitated if treated like a standard, unburned trauma patient.

Head Injury

Traumatic brain injury (TBI) continues to lead trauma statistics with high mortality rates and long-term disabling outcomes [29, 30]. Primary injury occurs at the time of the traumatic event, but secondary injuries to surrounding brain tissue can ensue and by avoiding further insults can be minimized. As always, no interventions should delay transfer to a neurotrauma center. While the Brain Trauma Foundation (BTF) guidelines [31] support advanced life support as opposed to basic life support transport, no data supports this statement. Ultimately, transport should be efficient and uphold the two main principles of the BTF guidelines: preventing hypoxia (SpO_2<90 %) and hypotension (SBP <90 mmHg). A large prospective database has demonstrated that a single episode of hypotension or hypoxemia, the strongest independent predictors of outcome, can double mortality and increase morbidity [32–35].

Management of the prehospital airway in a TBI patient is controversial and is dependent on the initial assessment of the patient. If the patient is being transported by ground in an urban environment and able to maintain SpO_2>90 % with only supplemental oxygen, data suggest that intubation with paralytics demonstrates equivocal or even worse outcomes [36–38]. Unfortunately, much of the remaining data on the topics of intubation and paralytics are observational, retrospective, and controversial leading to no best practice guidelines [39]. Risks of intubation include esophageal intubation with possible failure to recognize aspiration and delay in transport. This may also place personnel who do not frequently intubate in a high stress situation with potential for worsening patient outcome. Hypotension with induction medications and respiratory arrest should intubation fail are the downfalls of prehospital rapid sequence intubations (RSI).

These risks should not deter intubation in a severely injured TBI patient (GCS <9) as on-scene intubation may improve outcomes in the sicker patient [40, 41]. Should the patient require intubation, the responder with the most experience should intubate and use RSI if needed [42].

Historically, ketamine has not been used in TBI patients as it was thought to elevate ICPs. However, recent data suggests it may be a viable option to etomidate which causes vasodilatory effects leading to hypotension [43, 44]. Successful intubation should be confirmed both with clinical exam and with end-tidal carbon dioxide (CO_2) confirmation.

Traditionally, TBI patients would be hyperventilated to a partial pressure of carbon dioxide ($PaCO_2$) <30 mmHg, thus inducing vasoconstriction. We now know that maintaining a normal $PaCO_2$ of 35–40 mmHg improves outcomes. Only in the setting acute neurological change or impending herniation with signs such as unequal or fixed and dilated pupils, extensor posturing, or a decrease in Glasgow Coma Scale (GCS) >2 points should hyperventilation briefly be undertaken with a goal of $PaCO_2$ of 30–35 mmHg. While continuous end-tidal CO_2 monitoring is recommended, it still is not widely available in the prehospital setting. If not available, generally, 20 breaths per minute for an adult or 25 breaths for a child will achieve these goals.

Ideally, a Glasgow Coma Score (GCS) should be determined prior to administering sedatives or paralytics to the patient. Pupil exam should also quickly be performed, noting orbital trauma, asymmetry (>1 mm difference in diameter), or fixed pupils (<1 mm change with bright light). Resuscitation should be undertaken utilizing isotonic fluids. In a patient with a GCS <8 or with signs of impending herniation, mannitol (0.5–1 g/kg) or hypertonic saline (7 %, 1–2 cm^3/kg or 3 %, 3 cm^3/kg) may be given. Other maneuvers that can be beneficial in the treatment of TBI patients include minimizing noise and light stimulation, elevating of the head of bed/stretcher using reverse Trendelenburg, and loosening a constricting cervical collar (C-collar) to encourage venous drainage. Ultimately, outcomes following TBI are dependent on rapid transport to a neurotrauma facility with CT-scanning capability, intracranial pressure (ICP) monitoring and treatment, and available neurosurgical care.

Crush Injury

Crush syndrome is greatly underappreciated in trauma care. Specific compartments or the entire body may be crushed. It is the second most common cause of death after an earthquake, following asphyxia [45]. Much of the literature is a result of world-wide learning experiences following mass casualties such as earthquakes.

When approaching a victim of a crush injury, medical personnel should ensure their own safety first. If multiple victims are involved, medical attention should be directed to patients already freed, allowing rescue providers to extricate additional victims. First-line providers should be familiar with basic life support measures and ATLS principles. If the patient can be reached prior to extrication without endangering the medical provider or hindering rescue efforts, ideally, the patient should be assessed prior to extrication and frequently reassessed. Rescue deaths are patients that appear stable prior to extrication, but rapidly deteriorate following extrication thought to be due to reperfusion and systemic dissemination. Attention should first be directed at establishing large-bore intravenous access. Any limb may be utilized, intraosseous (IO) access if no IV can be established, and even subcutaneous infusion is possible at 1 cm^3/min if absolutely no other options exist. Isotonic saline should be used because even the minimal potassium in Lactated Ringer's can contribute to life-threatening hyperkalemia. While trapped, adults should be given 1 l/h of normal saline, children 15–20 cm^3/kg/h. If extrication takes longer than 2 h, fluids should be reduced to 0.5 l/h. The elderly, children, and patients with congestive heart failure and chronic kidney disease require less fluid. Other patient factors that may need more fluid include higher body mass indices, severely injured patients, delayed extrication, and higher fluid losses due to bleeding or hot weather.

On-scene amputation should not be performed to prevent crush injury—only to free a patient in a threatening situation such as impending structural collapse. A tourniquet may be placed just proximal to the amputation site to control bleeding. The most distal guillotine amputation should be performed, and intravenous ketamine may be used.

Communication with rescue personnel must be precise and extrication deliberate as life-threatening situations (bleeding, airway compromise) can arise. Patients who are trapped in Trendelenburg positions are especially at risk for rapid pulmonary edema and airway compromise. Once extricated, tourniquets may be applied for lethal bleeding, not to prevent the release of metabolites from the crushed tissue, and the usual precautions (spinal, airway, etc.) with rapid transport may commence.

Upon arrival to the trauma facility, assessment should follow the standard approach of ATLS. All wounds should be considered dirty with antibiotics and tetanus administered appropriately. Hypothermia should be avoided or corrected.

Consequences of crush syndrome include rhabdomyolysis, acute kidney injury (AKI), hyperkalemia, and compartment syndrome. Routine labs, specifically including basic metabolic function (BMP), lactic acid (LA), creatine kinase (CK), and urine pH, should be checked frequently, usually every 4–6 h. A creatine kinase >5,000 is an independent risk factor for acute kidney injury [46]. Hence, an indwelling bladder catheter should be placed to accurately measure urine output. Urine output for adults should be a minimum of 50 cm^3/h, ideally 100 cm^3/h. Normal saline is the preferred resuscitative fluid, and there is no data to support alkalinization of the urine with a bicarbonate drip or administration of mannitol to prevent AKI. Mannitol should not be used in anuric or hypotensive patients, but may have a role as a free radical scavenger and in decreasing compartment pressures. If given, assess the response to a small (25–50 g) dose; maximum benefit is achieved in about 40 min. Hyperkalemia is treated in the usual fashion, administering calcium to stabilize cardiac cell membranes. EKGs should be frequently utilized. Emergent dialysis may be necessary. Improved mortality has been demonstrated in trauma patients when dialysis has been started prior to a BUN >60 mg/dL (21.4 mmol/l) [47]. Nephrotoxic agents, hypotension, bleeding, and anemia should all be avoided in the oliguric phase.

Surgical treatment of crush injury includes fasciotomies and amputations. Fasciotomies can result in infection, thus increasing the risk of amputation, serous drainage and bleeding, and sensory and motor loss. Measurement of compartment pressures (>30 mmHg or <30 mmHg difference between the compartment and diastolic pressure) is the only objective indication for a fasciotomy. Subjectively fasciotomies may be performed if pain is out of proportion on exam or with passive flexion, loss of pulses, paresthesias, or if debridement of necrotic tissue is needed. If there is an underlying fracture, performing a fasciotomy converts this to an open fracture, and orthopedic consultation may be indicated. Delaying fasciotomies can lead to muscle loss and permanent sensory and motor deficits.

Amputations are performed in extremis situations—overwhelming rhabdomyolysis, myoglobin release, hyperkalemia, sepsis, or impending death. They should not be performed to prevent crush syndrome and the sequelae. If guillotine amputation is to be undertaken, it should be performed as soon as the above is recognized and often at the bedside due to patient instability. If the patient is too unstable, a tourniquet can placed and the extremity iced for a physiological amputation. Elective amputations may also be performed if major extremity trauma is present.

Conclusions

Damage control was first described as a surgical concept in an attempt to intercede prior to a patient reaching physiological exhaustion. This concept has since evolved into a resuscitative strategy from time of injury until definitive surgical repair. Of utmost importance to employing damage control as a concept is team collaboration that ensures efficient flow and care of the severely injured patient. It is essential to adhere to the damage control concept especially during special situations such as blast, burn, and crush injuries where the soft tissue destruction may distract from the life-threatening injuries.

Key Points

- Damage control surgery is the concept of staging interventions with early implementation to provide the best opportunity of salvaging a critically ill trauma patient.
- Effective communication is the cornerstone of providing a seamless transition from Ground Zero at the scene to the emergency department, control of bleeding and contamination in Part 1, resuscitation in Part 2 to achieving definitive repair in Part 3.
- Special circumstances such as burns, blast injuries, and traumatic brain injuries are evaluated in the same methodical manner, recognizing multiple cavities and life-threatening injuries can be present concurrently.
- Burns require aggressive resuscitation. The goal in traumatic brain injury treatment is to avoid secondary injury by preventing hypoxia and hypotension.

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Trauma Team Decision-Making

16

Morad Hameed and Larissa Roux

We choose to go to the moon in this decade … not because it is easy, but because it is hard, and because that goal will serve to organize and measure the best of our energies and skills, because that challenge is one that we are willing to accept, one we are unwilling to postpone, and one which we intend to win… [1]

ART OF WAR?
John F. Kennedy
Rice University, 1962

Introduction: A Well-Planned Journey into the Unknown

The arrival of a trauma patient to the resuscitation bay is one of the most high-risk and exciting moments in all of medicine. Trauma resuscitation is among the greatest clinical, technical, and logistical challenges in health care. Successful resuscitation depends on the efficient acquisition and analysis of clinical data and the rapid formulation of safe and actionable plans. Trauma teams must seamlessly transition from assessment and thoughtful planning to decisive action, which requires tight integration of multidisciplinary efforts and clear forward communication. This chapter focuses on the critical transitions in acute trauma care, starting with an analysis of how the basic physiologic principles of trauma resuscitation can form the foundation of effective decision-making under conditions of uncertainty and how these principles can inform the coordination of complex teams in the pursuit of critical and time-dependent priorities.

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The First Principles of Trauma Resuscitation

Consider the case of a 32-year-old male who is involved in a high-speed motorcycle crash on a highway outside a major city. He is initially assessed by a local emergency medical services (EMS) crew and is found to be obtunded and hypotensive, with a deep laceration over his anterior abdominal wall. Resuscitative measures are initiated, and a helicopter team is activated for rapid transport. The patient is transferred by air to a waiting trauma center, where he is initially found to be hemodynamically unstable, with a small amount of fluid on the FAST ultrasound examination and a pelvic fracture. The trauma team must decide what to do next.

Sequences like this, which take place every day in healthcare systems around the world, reflect the evolution of coordinated trauma care geared toward minimizing the duration and consequences of shock. Shock, or the interruption of adequate oxygen flow to tissues, is a leading cause of organ dysfunction, organ failure, and death in trauma, and delays in reversing shock are associated with potentially devastating secondary hypoxic injuries. Since the golden hour concept was first defined in World War I [2], the prompt care of injured patients, including minimization of the duration of shock, has become a first principle of trauma systems [3, 4]. It can be argued that modern trauma care, including prehospital care, transport, initial assessment, resuscitation, operative control of hemorrhage, and restoration of homeostasis in the ICU, is governed by the optimization of oxygen delivery and the reversal of shock (Fig. 16.1) [5].

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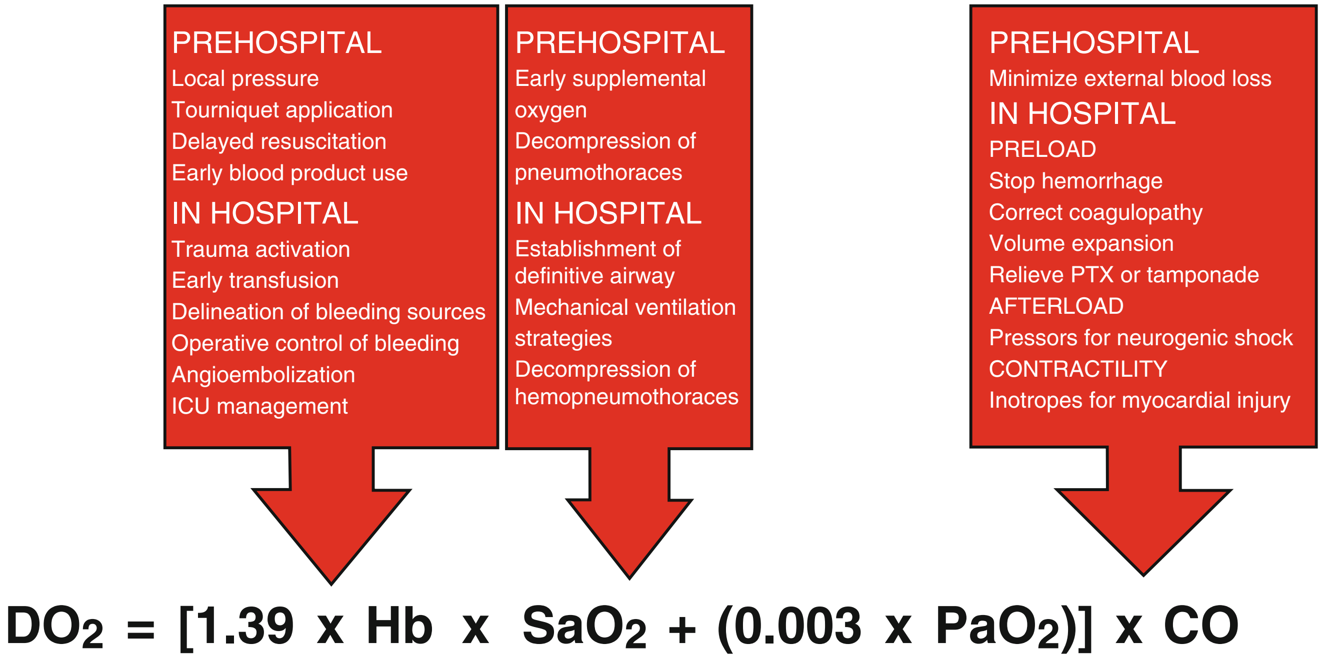

Fig. 16.1 First principles: Trauma care can be thought of as a coordinated effort to minimize the duration of impaired oxygen delivery and its far-reaching consequences. The major options for forward transfer (advanced resuscitation, imaging, operative or angiographic control of hemorrhage, ICU care) are all dedicated to the prompt reversal of shock. DO_2 = oxygen delivery, Hb = hemoglobin concentration, SaO_2 = oxygen saturation, PaO_2 = arterial partial pressure of oxygen, CO = cardiac output, PTX = pneumothorax

Since rapid restoration of oxygen delivery is a first principle of trauma care, it follows that all aspects of the structure and process of trauma systems should flow from it and be measured against it. EMS systems are geared toward the expeditious transfer of patients to appropriate facilities for definitive care and toward the efficient handover of patients to responding trauma teams. Effective trauma teams, in turn, coordinate the hospital-based trauma resuscitation, bringing all available resources and personnel (ED, diagnostic imaging, lab, blood bank, operating rooms, respiratory therapy, anesthesia, surgery, etc.) efficiently to the front lines and in the right sequence, to reverse the physiologic consequences of shock. They must maneuver a highly sophisticated and diverse response in conditions of uncertainty, where the depth and nature of shock are often unclear and where, amid the distractions of the resuscitation, more information is constantly arriving. The trauma team leader is at the eye of this storm, analyzing and reanalyzing information, determining a course of action, uniting the team around a common purpose, and paving the way forward.

Early Data Acquisition: The Primary Survey as a Decision-Making Tool

The handover from EMS is the first key transition point in the trauma resuscitation and can provide critical data on a trauma patient's ultimate disposition. A clear and concise handover is also the launch point for the primary survey and may direct the trauma team to issues requiring special focus and attention to detail.

The primary survey and its adjuncts are designed to provide high priority and immediately actionable clinical data, particularly regarding the presence or absence of shock and its likely causes [6, 7]. Mindful patient assessment and clear reporting of findings are at the core of the trauma team response. A single clinician should be designated to complete the primary survey and to report findings in a clear and concise manner. This communication is a key source of raw data that will guide the team in the major decisions that lie ahead. In some cases, as few as two data points are sufficient to prompt decisive action, for example, the presence of penetrating chest trauma and profound hypotension may trigger a decision to initiate a resuscitative thoracotomy. The primary survey should be concurrently completed and reported within a few minutes and should be repeated until a clear picture of injury pattern has emerged, key assessments have been completed, critical interventions have been performed, a measure of stability has been attained, and onward disposition has been determined. The adjuncts to the primary survey (Table 16.1), once completed, are important sources of information in the resuscitation effort. Their results should be announced and documented as each becomes available and, where possible, should be prominently displayed.

The primary survey and its adjuncts should begin to create a clear picture of a trauma patient's clinical status

Table 16.1 Adjuncts to the primary survey as shock resuscitation tools

Adjunct	Application in shock resuscitation
ECG	Blunt cardiac injury, acute versus chronic cardiac disease (e.g., acute coronary syndrome)
SaO_2	Peripheral perfusion
BP	Presence of shock
ABG	Base deficit—presence of shock
	Lactate—presence of shock
$EtCO_2$	Tube placement, adequacy of circulation
Gastric	–
Foley	Urine output for severity of shock
CXR	Evaluate sources of hemorrhagic shock
PXR	Evaluate source of hemorrhagic shock
EFAST	Evaluate source of hemorrhagic shock
T	Adjunct treatment in hemorrhagic shock

SaO_2 arterial saturation, *BP* blood pressure, *ABG* arterial blood gas, *$EtCO_2$* end-tidal carbon dioxide, *CXR* chest X-ray, *PXR* pelvic X-ray, *EFAST* extended focused assessment with sonography for trauma T temperature

and should begin to outline and prioritize available courses of action. Each new data point will further support or refute a trauma team leader's hypothesis regarding the nature and severity of shock and will refine the decision-making process.

Weighing the Options

While the emergency department (ED) is an appropriate place for the initial assessment and early resuscitation of trauma patients, it is not a place for definitive diagnosis or treatment, and no strong gains in either area will be made as long as patients are left there. In general, time in the ED should be minimized. However, as soon as a patient is moved from the resuscitation area, he or she will encounter new risks that must be weighed against the benefits of this movement.

For hemodynamically unstable patients, the choice of transfer destination is relatively straightforward. Shock patients exhibiting either no response or a fragile transient response to early resuscitative measures should be taken immediately to the operating room (OR). A single hypotensive episode, which reflects over 1500 mL of blood loss, may be enough to determine the presence of hemodynamic instability, although some clinicians will add an assessment of metabolic acidosis (base deficit, lactate) to more definitively confirm the presence of shock before making a commitment to go to the OR [8]. The decision to go to the OR with an unstable patient can occur early on in the course of the resuscitation, often on the basis of only a few data points, and in this case, the remainder of the resuscitative effort is dedicated to getting the patient ready to move, ensuring that key details of the resuscitation are completed (e.g., adjuncts to primary survey, cross match), and preparing the accepting team in the operating room for the next phase of patient care. The transition to the operating room is described in more detail below.

For patients with relative hemodynamic stability, the decision to pursue an operative intervention is not as urgent, and there are more diagnostic and therapeutic options available. It should be remembered however, that many of these patients, particularly those who have been injured recently, may still be in compensated shock, with undetected ongoing bleeding. Any evidence of hemodynamic deterioration should redirect patients to an operative algorithm. Until such deterioration occurs, trauma teams will be faced with the following six options:

1. *Sit tight and wait for a signal*: When a patient's hemodynamic status is unclear, a period of intense watchful waiting in the secure surroundings of the trauma resuscitation area may be warranted. It should be emphasized, that this is a period of active observation, with serial determination of vital signs, repetition of the physical examination, and serial determination of the presence of occult shock through the measurement of base deficit and lactate, with special focus on how these parameters respond to initial resuscitation. The primary survey should be iterative, and the results of the adjuncts should be carefully reviewed to determine potential etiologies for shock. During a brief period of watchful waiting, the appropriate transfer destination may become clear—a patient considered to be a transient responder may need to go to the operating room, while a stable patient may be safely transferred to CT for definitive imaging.
2. *Computed tomography*: Taking a trauma patient to CT is a well-known pitfall in trauma care. Trauma teams should always recognize the potential for a patient in compensated, undetected shock to decompensate in the scanner, where access to the patient can be limited and resuscitative equipment and personnel are less available. However, the speed of modern CT scanners and their geographic location, often steps away from the resuscitation area, have reduced the risk of a trip to CT. The advantages of CT, both for blunt trauma as a definitive imaging tool and penetrating trauma, to map trajectory and establish follow-up diagnostic and therapeutic approaches, are great. Still, trauma teams must confirm hemodynamic stability before traveling to CT.

   Since CT is a default path for the majority of stable multi-trauma patients and since it is a time-dependent priority in patients with traumatic brain injuries, resuscitative efforts in the primary survey are often directed toward moving the patient efficiently from the trauma bay to CT. The TTL should remain vigilant about and immediately address lulls in the progress of this transfer. If there is any concern about the need for operative intervention after the scan, the OR and relevant surgical services (e.g., neurosurgery) should be informed and on standby so that a time-consuming transfer back the ED can be avoided.

3. *Angiography*: The role for angiography in unstable patients is limited to a very few clinical scenarios. Some groups of investigators have advocated for the use of angiography for the control of hemorrhage in patients with solid organ and pelvic injuries whose hemodynamics can be maintained with active resuscitation (transient responders) [9, 10]. However, extreme caution must be exercised when contemplating such a move, and the full spectrum of resuscitative capabilities and personnel should be transferred to the angiography suite along with the patient. Resuscitation can be difficult under these circumstances, with a sterile field and radiography limiting access to the patient and without the usual equipment available for resuscitative procedures. Furthermore, since most hemorrhagic injuries of the liver and pelvis are venous, angiography may be of limited utility in many of these injuries. That said, if no surgically accessible injuries are identified in the primary survey and a patient's hemodynamic stability can be maintained with a carefully controlled resuscitation, the risks of angiography may be justifiable. In general, angiography usually follows CT, where contrast extravasation in the arterial phase pinpoints specific areas of active arterial hemorrhage, and CT rules out the immediate need for operative intervention [11]. For patients with suspected pelvic fractures and bladder injuries, pelvic angiography should be completed before retrograde urethrograms or cystograms to ensure vascular contrast extravasation in the pelvis can be detected.
4. *Operating room*: The operating room is an ideal destination for patients in shock. With dedicated surgeons, anesthesiologists and nurses present, and a full spectrum of resuscitative options and equipment available, resuscitation can be intensified and titrated against continuous hemodynamic monitoring. With better lighting, sterile technique, and equipment, procedures such as chest tube and line placement, exploration of wounds, and completion of resuscitative thoracotomy can be done more safely and more precisely. However, for unstable patients, a partially unmonitored move to an incompletely prepared operating theater can be hazardous. Transfer to the operating theater is a critical transition (Fig. 16.2), whose benefits can be maximized by careful mitigation of risks. Some trauma centers have full operating theater capabilities in the resuscitation area, allowing the resuscitation to blend seamlessly with definitive surgery for damage control. Locating surgical capabilities in the resuscitation area has been associated with better outcomes for some of the most unstable patients [12]. When such capabilities are not available, it may still be possible to create a smooth transition between the trauma bay and the

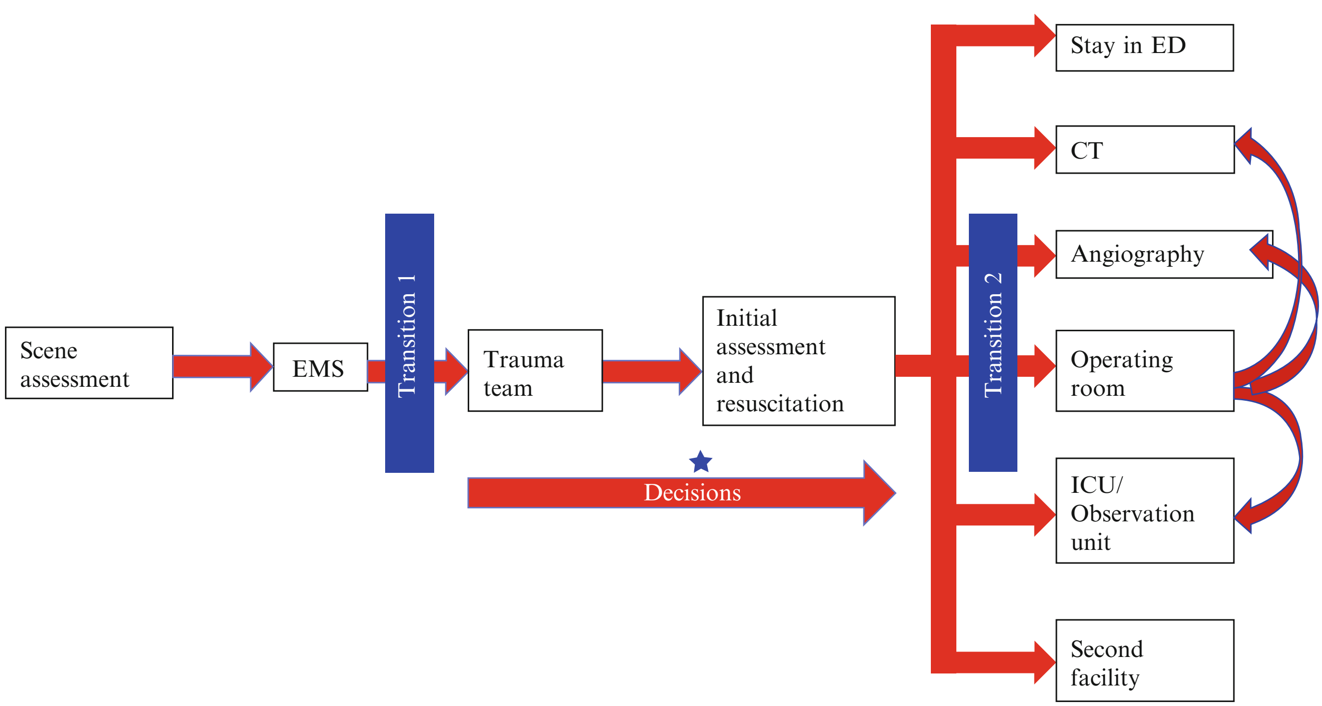

Fig. 16.2 The process of trauma care: key transitions and decision points. Early decisions regarding the need for damage control resuscitation, massive transfusion, and disposition from the trauma bay and (onward) can be made very early in the course of resuscitation

Fig. 16.3 An example of a checklist describing key priorities before transfer from the trauma bay to the operating room

CHECKLIST
preparation for damage control surgery

	Pre operative briefing: case discussed with OR and anesthesia
	Advise blood bank of move to OR
	Thoracic, cardiac and vascular instruments
	Cell saver
	Warm room
	Perfusion technician notified if needed?

operating room. The OR should be part of the trauma activation callout and OR personnel, including anesthesia and nursing, should begin to arrange operative capacity for a potential imminent transfer. The trauma team leader and the OR should be in close communication throughout the resuscitation, and the decision to transfer to the OR and the anticipated resource and equipment needs should be specified as early as possible (Fig. 16.3). Some operating theaters have prespecified trauma laparotomy trays, complete with vascular and thoracic instruments, along with appropriate retractors, and even sternal saws that can be rapidly opened as needed. It is important that the OR setup for trauma is predefined, but even if it is, it is useful for the TTL to conduct a briefing to ensure that the assembled team is aware of the risks, expected operative strategies, and anticipated equipment needs. Ideally, the trauma patient will arrive from the trauma bay to a fully staffed, warm operating room, with monitoring interfaces and operative instruments set up and ready to go. Even, or perhaps especially, in this operative crisis situation, a preoperative briefing and a time-out, as defined by the WHO Safe Surgery Saves Lives campaign, are essential to set the direction for the case [13].

In some cases, a thorough primary survey, including chest and pelvic X-rays and an extended focused assessment with sonography for trauma (eFAST) ultrasound exam of the chest and abdomen, may not reveal a clear, single cause of hemodynamic instability, and an unstable patient may arrive in the operating room without a clear operative plan. Some operating rooms are equipped with diagnostic modalities and expertise, including transesophageal echocardiography, X-ray, ultrasound, interventional radiology, and an upper and lower gastrointestinal endoscopy to quickly repeat or intensify the workup of undifferentiated trauma patients. When the source of hemorrhage is difficult to identify (when diagnostic imaging is not directive), the abdomen is the usual suspect. Investigators at the University of Southern California (USC) observed that exploratory laparotomy was required much more frequently than exploratory thoracotomy (89 % versus 1.9 %) for unstable patients with thoracoabdominal trauma. They suggested abdominal exploration should be prioritized over thoracic exploration in this instance [14]. The team should, however, be prepared to do both, although this was rarely required in the USC series (2.1 %).

Operative interventions in hemodynamically unstable patients should have defined objectives and clear onward disposition options. Hemodynamic instability is often associated with acidosis, coagulopathy, and hypothermia, which justify a damage control surgical approach that prioritizes early control of hemorrhage and contamination and abbreviation of operative efforts [15]. TTLs can decide on this course of action even before a patient's arrival in the operating room and should know the onward disposition from the operating theater even before a patient arrives there. For example, if a traumatic brain injury was suspected, but a CT of the head could not be obtained in advance of an urgent exploratory laparotomy, arrangements can be made for immediate postoperative transfer to CT. Alternatively, if a patient with a complex pelvic fracture is taken to the operating room for thoracic or abdominal injuries, the interventional radiologists and angiography suite can be readied in advance for possible direct transfer from the operating room to the angiography suite. Finally, if operative intervention has been successful in controlling hemorrhage, aggressive restoration of homeostasis is best accomplished by rapid, seamless transfer to a briefed and prepared intensive care unit (ICU).

5. *Intensive care unit*: The ICU is almost inevitably the ultimate target for trauma patients with hemodynamic instability. It is here that oxygen delivery, especially within the first few hours after injury, can be promptly and judiciously restored, where coagulopathy and acidosis can be readily corrected, and where organ injury and organ

Fig. 16.4 An example of a checklist describing key priorities before inter facility transfer of a critically injured trauma patient

CHECKLIST
preparation for trauma patient transfer

	EMS report included
	Primary and secondary survey documents completed
	Radiology findings documented and images uploaded
	Spine precautions for transportation documented
	Verbal handover completed. Name of accepting physician: ____________

failure can be supported. The ICU team should be aware of the arrival of critical trauma patients in the ED and should track their progress through the first phases of assessment and treatment. Failure to engage the ICU team early will result in poor appreciation of the pattern and severity of injury, which may lead to delays in achievement of resuscitation targets. In a damage control surgery/damage control resuscitation situation, onward disposition from the ICU is a critical matter as well. Surgical teams may require staged operative approaches to ensure hemostasis, complete repairs, and accomplish abdominal or thoracic closure. In recent years, close collaboration between ICU and trauma teams with respect to fluid balance and increased dedication to abdominal wall closure have, in some series, led to near-universal abdominal closure rates [16]. Surgical teams should be prepared to return their patients to the operating room for definitive repairs the moment homeostasis has been achieved and should return at high frequency until reconstructions are complete. For evidence of persistent hemorrhage, as evidenced by ongoing high transfusion requirements, surgical teams should have a low threshold to return to the operating room, in particular, if bleeding continues after the correction of coagulopathy and hypothermia.

6. *Transfer out*: One of the key priorities in the initial assessment of trauma patients is to determine whether definitive care of all of the injuries will be possible at the admitting facility. Trauma team leaders should make themselves familiar with local and regional trauma expertise and resources ahead of time and, as soon as the injury pattern is established, should determine the need for and the mechanics of transfer to a referral facility. Transfers should be initiated early and should occur along preestablished referral pathways in an integrated trauma system, where the capabilities and roles of each hospital are already known and designated. The arrangement of transfers has two logistical challenges: arranging the transport, and communicating initial findings to the receiving hospital. Both of these challenges must be addressed early, concurrently with resuscitation, so that once the initial phases of resuscitation have been completed, patients are ready to move, in a controlled fashion, and without significant delay. A safe and seamless transfer depends on accurate and complete communication between referring and receiving facilities. Often, in the heat of resuscitation and the push to move patients out, the completion or communication of certain details can be missed [17]. In a survey of trauma personnel in our trauma system, 67 % of respondents felt that incomplete communication at the time of trauma patient transfer was a potential source of critical delays in appropriate care and serious adverse events. We also found that inter-facility trauma patient transfer was often characterized by loss of information from the scene and even from the referring hospital. Trauma transfer protocols and checklists may help to ensure completeness of care, documentation, and forward communication and may therefore make trauma care safer and more seamless (Fig. 16.4).

The Anatomy and Physiology of a Decision

A thorough understanding of physiological principles and the available options for definitive care are the basic prerequisites for effective decision-making in trauma resuscitation. All of the transfer destinations outlined above are legitimate options under the right circumstances, and very often, a combination of destinations must be selected. TTLs and trauma teams must carefully weigh incoming physiologic and anatomic data in order to define the best possible course (and specific sequence) of action. In general, clinical decision-making must merge available patient data with the best available scientific evidence, plotting a course based on unique patient circumstances and efficacy and safety of competing therapies. In trauma, this decision-making process has both heightened importance and is greatly accelerated.

TTLs and trauma teams making critical transfer decisions under conditions of extreme uncertainty have several decision support tools at their disposal. While no two trauma patients are identical, these tools apply the best available evidence and thought processes to standardized situations that may help to inform real-world decision-making. We will briefly consider three types of tools: predictive scores, clinical practice guidelines, and decision analysis methods.

Predictive scores help to process raw clinical data in order to inform complex decisions. One of the most familiar of these, the Glasgow Coma Scale, merges neurologic findings to give health-care teams an indication if a trauma patient is alert enough to protect his/her airway and if a definitive airway might be urgently needed. Similarly, the ABC score (penetrating mechanism, blood pressure, heart rate, FAST ultrasound) [18] and the TASH Score (sex, blood pressure, heart rate, FAST ultrasound, hemoglobin, base deficit, fractures) [19] combine physiologic and anatomic data to bring evidence and clear rationale to the activation of trauma exsanguination (massive transfusion) protocols.

These scores may focus resuscitation teams on key, predictive variables, thereby facilitating more evidence-based judgments. For example, a male patient with a hemoglobin < 9 g/dL (90 g/L), base excess < −6, SBP < 100 mmHg, HR <120, and a positive FAST exam has a TASH Score of 17/28 and would be expected to have a 43 % chance of requiring a massive transfusion [20]. While this probability on its own may not be compelling enough to prompt activation of a trauma exsanguination protocol, it does bring a constellation of data into an evidence-based decision process.

Clinical Practice Guidelines (CPGs)

Clinical practice guidelines (CPGs) are algorithms [21] for the major possible trauma scenarios and attempt to synthesize the best available evidence and the best available judgment into safe and efficient strategies to advance patient care (Fig. 16.5).

But the decision to transfer a patient out of the trauma bay, toward more definitive care, perhaps one of the most complex decisions in medicine, is not easily informed by

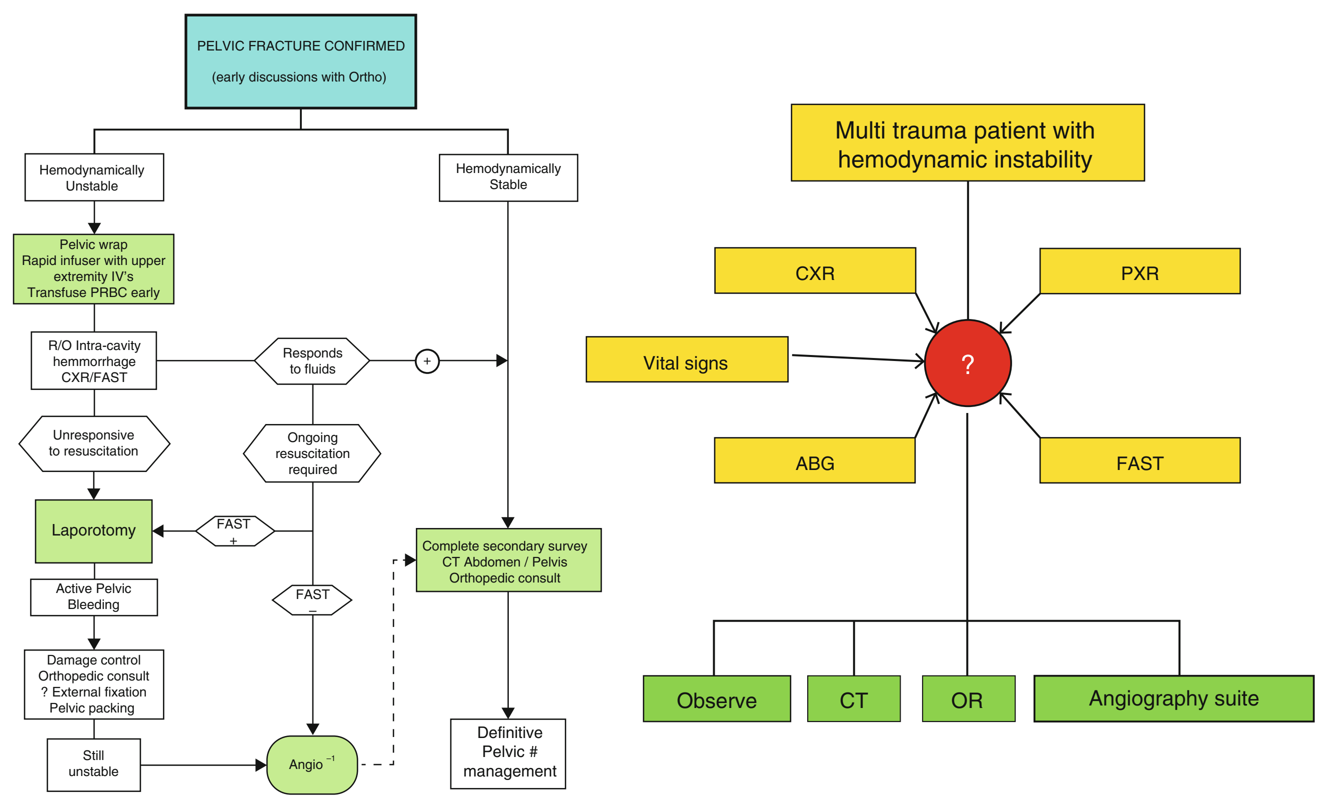

Fig. 16.5 Clinical decision-making under conditions of uncertainty: integration of anatomic data (chest X-ray (CXR), pelvic X-ray (PXR), FAST), and physiologic data on response to resuscitation (arterial blood gas (ABG), vital signs) guides movement down the clinical pathways and to the ultimate destinations (shown in *light green*)

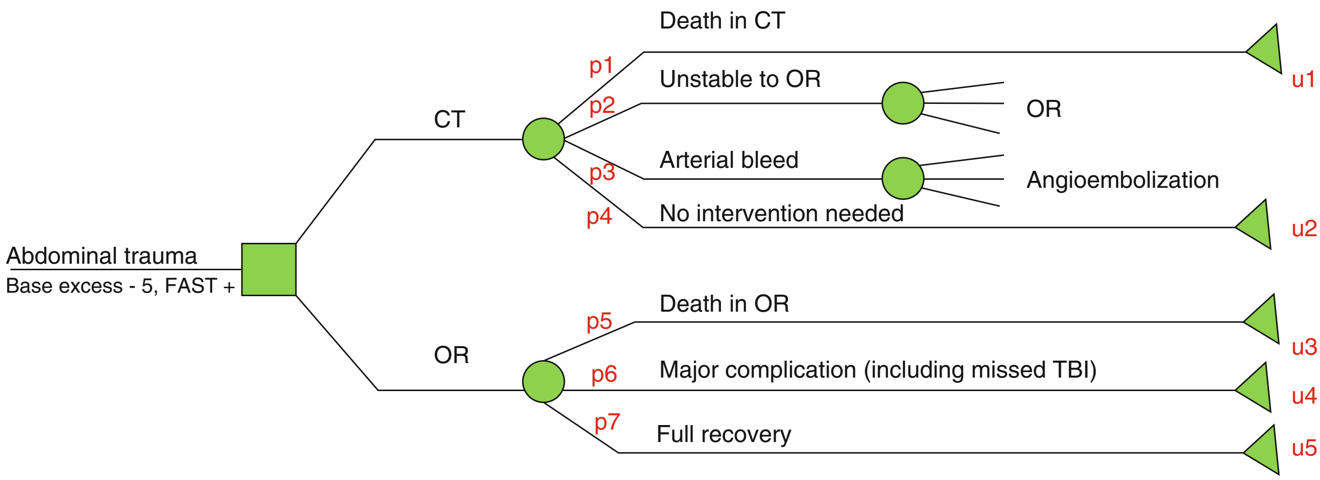

Fig. 16.6 The anatomy of a decision: lessons from decision analysis. This is the age-old decision about whether to take a transiently responsive trauma patient to CT or to the OR. While critical decisions in the trauma bay are often made based on judgment and pattern recognition, every major decision can be broken down into its component elements and analyzed based on the best available probability and outcome data. The probabilities "p" will be modified based on emerging physiologic data and will in turn influence the proportion of patients reaching each health utility "u" state. In this example, indicators of shock (base deficit) or active bleeding (FAST exam) may make p1 and p2 and their outcomes prohibitively higher than p5 and p6, supporting a decision to go to the OR. Currently, TTLs weigh these probabilities subconsciously, but information technologies may eventually be able to provide and adjust probabilities in real time, to increase the objectivity of decision-making. Square = decision node, circle = probability node, triangle = outcome node

simple or even multivariate scores, and the specific decision points within CPGs still depend on analysis of data and individual judgment (Fig. 16.6). Data points used to inform the decision arrive in real time, can rapidly change over time, and can be unreliable. The decisions themselves, even if based on perfect data, are complex. While all clinical decisions are made under conditions of uncertainty, decision-making in trauma often occurs under conditions of extreme uncertainty, making judgment and personal experience big factors in the determination of strategy.

The science of *decision analysis* applies explicit and quantitative methods to analyze decisions made under conditions of uncertainty. Figure 16.6 explores the decision to move a patient from the trauma bay to the CT scanner or to the operating room, a frequent challenge encountered by TTLs. While all the inputs into this decision and the consequences of this decision are difficult to map out in an embedded figure, the exercise of doing so can help decision-makers gain some depth of understanding about the decision process. The raw data to calculate the probabilities for the chance nodes of this decision tree already exist in the literature. Decision-making tools in the future may be able to harness the data collection, computing, and analytic power of new information technology tools not only to populate the probabilities but also to modify these probabilities and inform clinical decisions based on accumulating data in real time.

Regardless of what decision-making strategy is used, TTLs should strive to take an active role in the decision-making process. Even incorrect decisions will provide information that will shape subsequent decisions. Decision-making is a dynamic and iterative process that requires close observation and continuous refinement. For example, if a patient's blood pressure drops as he is being readied for CT and outcome probabilities change, the decision-making process and the team should be agile enough to rapidly redirect him to a waiting operating room. The team would have been observing the patient intently during the transfer process, watching for new information, keeping options open, and modifying the plan accordingly. As long as TTLs and trauma teams are keenly aware of emerging data and the effect of decisions, a wrong decision is better than no decision.

Trauma Team Leadership: Translating Decisions to Action

There are three essential aspects of trauma team leadership: continuously gathering and processing information from an array of sources to create a clear vision about the priorities of care, making decisions based on this information, and inspiring and coordinating the trauma team to enact these decisions. The process of transforming raw data to clear vision and finally to concerted action is examined in Endsley's exploration of the concept of *situation awareness*, which he defines as "the *perception* of elements in the environment within a volume of time and space, the *comprehension* of their meaning, and the *projection* of their status in the near future." This process, which involves taking disjointed data elements regarding the status and dynamics of a situation, integrating them into a comprehensive picture, and then predicting and addressing future developments, is a fundamental responsibility of the trauma team leader. To do this well, the TTL must promote an environment of open and clear communication and must be able to step back from the resuscitation enough to achieve and act on situation awareness [22].

It is helpful for both inexperienced and experienced trauma teams to be aware of all relevant data as these data are collected, and periodic summaries of clinical status can reduce uncertainty and anxiety and inspire confidence in team leadership considerably. It is also extremely helpful for the team (and the TTL) to communicate the anticipated threats and the rationale for decision-making, even if the decision may subsequently be revised. A decision-making rationale statement may be something like this:

This is a 32-year-old man involved in a motorcycle crash with transient hemodynamic instability possibly due to intra-abdominal hemorrhage or pelvic fracture based on our FAST exam and pelvic X-ray. We have secured his airway and have good IV access, with O negative blood infusing. CT is ready for us. Our priorities are to logroll him, place an orogastric tube and a Foley catheter, and prepare him for transfer to CT within the next 5 min. But I am still worried about ongoing bleeding and we should keep an OR on standby.

This statement clarifies a TTL's thinking and priorities and brings the team in on the decision-making process creating a shared mental model (Chap. 4) thus allowing the team to simultaneously prepare for multiple possible scenarios. It is an essential way to prepare a complex resuscitation and multidisciplinary team to transition seamlessly between therapeutic alternatives.

The style of leadership that engages the vision and talents of team members and unifies them behind a singular purpose has been described by Collins in a study of highly successful companies. Collins' research team noted that companies that were able to negotiate adversity to achieve dramatic growth, consistently had leaders with a "paradoxical" combination of great personal humility and strong professional will to achieve sustained results. The researchers considered this combination to be at the pinnacle of the hierarchy of leadership attributes and called it Level 5 leadership. The ability of a trauma team to acquire and share knowledge and to seamlessly deliver complex, integrated, lifesaving care may depend on a similar style of open and humble leadership and an unwavering focus on process and goals [23].

Forward Communication and Handover

One of a TTL's essential roles is to pave the way forward for the patient and the team. Forward communication should commence even before a patient's arrival or very early during a patient's assessment. Vital time is lost, and the duration of shock prolonged, if this role is neglected. Forward communication starts with the automatic alerts of all essential services, including emergency medicine and surgical teams, radiology, lab, blood bank, OR, and ICU. However, as therapeutic priorities become clearer, the TTL must move beyond the automatic alerts to customize the response. This may mean ensuring that the CT scan is clear and that the radiologists are aware of the studies needed and the suspected injuries. It may include ensuring that an operating room is being set up and that anesthesia is aware of the status of the resuscitation. It may include letting the interventional radiologist know that the patient may be coming to the angiography suite directly from CT. Besides being the architect of a dynamic plan, the TTL must coordinate seamless transitions in resuscitation and definitive care. As noted, this forward facilitation may save hours of shock and its many downstream complications.

Special Considerations in Mass-Casualty Situations

Mass-casualty situations are discussed in detail elsewhere in this text (Chap. 26). By definition, these events overwhelm the usual processes of emergency trauma and surgical care [24]. However, the essential considerations for transfer to definitive care remain the same. Individual trauma teams designated for each arriving patient must assess their patients and develop specific strategies. The overall TTL, who must remain above the fray of individual trauma resuscitations, will pave the way forward for each team by activating all potential downstream pathways simultaneously, then directing patients forward based on level of acuity and other considerations. A considerable part of the TTL's time will be spent on the telephone activating pathways and providing forward communication, thereby ensuring that an institution-wide response flows as seamlessly and efficiently as possible. The same principles, of identifying the presence of shock and minimizing its duration and of making the best decisions possible under dynamic and uncertain considerations, still apply, only on a larger scale.

Future Directions: The Role of Information Technology

The formulation of trauma resuscitation and transfer strategies represents the pinnacle of multimodal patient assessment, decision-making under conditions of uncertainty, and team leadership. A wealth of experience has accumulated in each of these areas, and trauma centers around the world have applied this experience, increasingly combining it with predictive tools and decision-making algorithms, to address

Table 16.2 Early resuscitation process measures from the American College of Surgeons Trauma Quality Improvement Program

Trauma quality improvement process measures
Measurement of best Glasgow Coma Scale (GCS)
Time to operating room for hemorrhage control
Time to angiography for hemorrhage control
Transfusion in the first 4 h (packed red blood cells (pRBCs) and fresh frozen plasma (FFP))

shock from complex, multisystem trauma with a prompt, aggressive, high-quality response (Table 16.2). New information technology tools may have the capacity to optimize the use of data in clinical decision-making, bring tailored trauma response algorithms to the bedside, and enhance communication at the critical periods of transition between the emergency department and definitive care [25, 26].

Conclusions

Trauma resuscitation represents more than simply the care of injured patients, although this in itself is an important function. Each trauma resuscitation is a coordinated, multidisciplinary effort and a powerful application of hospital's resources in a complex and time-dependent situation. Each trauma resuscitation serves "to organize and measure the best of our energies and skills," and every trauma team and hospital and every patient, not just trauma patients, stand to benefit from the measurement and improvement of process and outcome measures in trauma care.

Key Points

- Trauma team leadership, decision-making, and organization are based on fundamental physiological principles including prompt reversal of shock and minimization of secondary injuries.
- Early critical decision-making is based on data elements gathered during the primary survey, and it is essential for these findings to be communicated and understood clearly as a shared mental model develops.
- A picture of trauma patient disposition often develops early as primary survey data accumulates. Early diagnostic imaging adjuncts to the primary survey may also be directive. The trauma team should gear itself toward one of six disposition strategies very early on in order to avoid potentially life-threatening decision-making and logistical delays: watchful waiting, CT, interventional radiology, operating room, ICU/trauma unit, or transfer to another facility for definitive care.
- Unstable patients are best managed in the operating room.
- Forward planning and forward communication should begin very early in the course of assessment and resuscitation.
- Decision-making under conditions of uncertainty can be guided by careful consideration of risks and benefits of the various possibilities based on emerging information. These decisions are often based on judgment and experience, but may increasingly be informed by predictive analytic tools.
- Trauma team leaders should maintain situation awareness and pursue an open model of leadership that encourages communication, engages team members to maximize their potential, and establishes and pursues a shared common purpose.

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17 Emergency Critical Care Procedures

Paul B. McBeth and Morad Hameed

Introduction

The purpose of this chapter is to highlight selected emergency critical care procedures. Topics covered include surgical airway management, vascular access, tube thoracostomy, resuscitative thoracotomy, and diagnostic peritoneal lavage. Detailed step-by-step descriptions of the individual procedures can be found in almost all surgical, emergency, or critical care texts and are beyond the scope of this chapter. Instead what follows is a practical discussion of indications, contraindications, and most importantly controversies and common pitfalls involving these procedures with references to appropriate detailed descriptions provided.

Emergency Procedures and Team Dynamics

As discussed in Part 1 of this text, the team architecture and dynamic are centered around a trauma team leader (TTL) whose responsibility is to provide oversight in the management of critically ill patients. The TTL directs the flow of the resuscitation, including the selection and prioritization of life-saving procedures, based on the patient's presentation and information gathered by other care providers. When possible, the TTL should avoid engagement in specific procedures in order to facilitate a cohesive flow of the resuscitation, but should instead remain aware of the capabilities of team members and up to date on procedural progress and success. Since emergency procedures conducted on critically ill or injured patients require speed and efficiency in order to provide the greatest chance of successful patient outcome, the most skilled team member is usually selected to carry out these procedures. In the event where the TTL is the only team member present capable of performing a necessary procedure, temporary delegation of the leadership role to an alternate team member should be considered to avoid fixation errors (Chap. 5). Specific roles of each team member should be determined and rehearsed beforehand. Regular simulation-based training is helpful to establish these roles as well as to determine group dynamics, closed-loop communication with specific emphasis on procedure delegation and reporting (Chap. 4), and familiarization with equipment and awareness of institutional protocols. Clear communication is more important than ever when resuscitating critically ill patients and performing emergency procedures. All reasonable efforts should be made to ensure that emergency procedures remain controlled, organized, and safe; incorporate sterile techniques; and consider patient safety and comfort. The health and safety of each team member is also paramount. Personal protective equipment should be worn in all emergency procedures including gowns, gloves, eye wear, and when appropriate lead aprons. Unnecessary procedures should be avoided due to the risk posed to trauma team members. Post procedure debriefings are helpful to support learning and ensure quality assurance for improved patient outcomes. It is also important to realize personal limitations, and seek help if unfamiliar with some of the more invasive procedures.

Airway Management

Emergency surgical airway management is an essential skill required by care providers of critically ill patients. A surgical airway is generally considered a procedure of last resort when alternative attempts to capture a patient's airway have failed.

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The criteria prompting the need for surgical airway management is best summarized by the "can't intubate, can't ventilate" dictum where the care provider is unable to intubate or provide effective bag mask ventilation. In particular, sustained hypoxemia during intubation efforts provides justification for initiation of surgical airway procedures. Other indications for surgical airway management include severe facial or nasal injuries, massive facial trauma, possible cervical spine trauma preventing adequate ventilation, anaphylaxis, and chemical inhalation injuries. There are no absolute contraindications to surgical airway management; however caution should be considered in patients with known underlying anatomical abnormalities, tracheal transection, and acute laryngeal disease due to infection or in small children under the age of 10 years [1, 2].

Emergency surgical airway management is often performed in critically ill patients necessitating time-sensitive management of the airway in an often austere environment [3]. Given the urgent need for the procedure, availability of resources is often limited. If time permits, the ideal location for surgical airway management is in the operating room (OR) where appropriate access to surgical instruments, anesthetic supplies, support teams, and lighting are available.

A cricothyroidotomy is the procedure of choice in an emergent situation when unable to intubate. This is done through the cricothyroid membrane, which in most patients is straightforward to identify on direct palpation of the neck. This technique allows avoidance of the vocal cords, thyroid isthmus, and associated vessels. There are three main approaches to cricothyroidotomy: needle cricothyroidotomy, percutaneous cricothyroidotomy using the Seldinger technique, and surgical cricothyroidotomy. Detailed step-by-step descriptions of these procedures can be found elsewhere [4]. The decision of which approach to use is guided by both the patient's condition and familiarity of the care provider with the procedure. The needle cricothyroidotomy technique is limited by the volume of gas exchange through the catheter and the need for a high-pressure gas source for jet ventilation; therefore its effectiveness at ventilation is limited while its capability to provide oxygen delivery is favorable. This technique serves as a useful time bridge towards establishing a definitive endotracheal intubation and is the preferred method of securing a crash airway in infants and young children where surgical cricothyrotomy is contraindicated. Percutaneous cricothyroidotomy using the Seldinger technique and surgical cricothyroidotomy are both equally effective at securing an airway. It should be noted that some commercially available percutaneous cricothyroidotomy sets do not have cuffed tubes, which may limit airway protection and ventilation until conversion to a more definitive airway is possible. In the authors' experience, percutaneous cricothyroidotomy, which requires some force for tube placement over the wire, without direct visualization of the airway, is a less controlled procedure than open cricothyroidotomy. For both procedures, we recommend a vertical incision, which can be extended based on palpation of anatomic landmarks, and which may help avoid the anterior jugular veins. The selection of percutaneous or open methods is dependent on the availability of equipment and skill of the operator. Once the procedure is complete, confirmation of location is essential prior to commencement of ventilation to avoid insufflation of false passages. This can be done using a bronchoscope for direct visualization, in-line capnography for confirmation of end-tidal CO_2, or small-volume ventilation with an ambu-bag with bilateral lung auscultation [2].

Once the surgical airway has been captured, the cricothyroidotomy should be evaluated by a surgeon to assess for injury to the airway and neighboring anatomical structures. This assessment is conducted in the OR followed by conversion to a tracheostomy. This helps to avoid the long-term complications of glottic or subglottic stenosis, laryngeal stenosis, tracheomalacia, and dysphonia [4]. Early post-procedure complications include bleeding, subcutaneous emphysema, obstruction, esophageal or mediastinal perforation, aspiration, vocal cord injury, pneumothorax, and posterior tracheal wall perforation [4, 5].

Surgical airway management is a potentially life-saving skill and should be part of the training repertoire of any surgeon, emergency medicine, or critical care physician. Given the low incidence of surgical airway management, alternative training and credentialing modalities are needed including phantom model, human cadaver, and animal simulation [6].

Tube Thoracostomy

Tube thoracostomy is the insertion of a tube into the pleural cavity to facilitate drainage of air and fluid. This procedure serves as both a diagnostic and therapeutic intervention. In critically ill patients with undifferentiated shock rapid bilateral chest tube drainage, even before chest X-ray evaluation, is a useful procedure for guiding diagnostic evaluation. Other indications for tube thoracostomy include pneumothorax, hemothorax, hemopneumothorax, hydrothorax, chylothorax, empyema, pleural effusion, and prophylactic decompression for patients undergoing air transport [7–9]. There are no absolute contraindications but relative contraindications include coagulopathy, pulmonary bullae, loculated pleural effusion, empyema, or pulmonary, pleural, or thoracic adhesions. If there is history of previous thoracotomy or thoracostomy drainage one should exert additional precaution during insertion as the likelihood of pulmonary adhesions and loculated collections is higher. This in turn leads to an increased risk of potential complications from chest tube placement. The size of tube placement dictates the surgical technique used. Small pigtail drains are placed using CT or ultrasound guidance using the Seldinger technique [10]. Larger surgical drains are placed under direct visualization with a surgical approach involving tissue dissection. Detailed descriptions of procedural steps for tube thoracostomies are provided elsewhere [11].

Controversies

Despite numerous studies the use of prophylactic antibiotics, appropriate tube size selection, and management of occult pneumothorax remain controversial topics.

Antibiotics

The need for prophylactic antibiotics prior to thoracostomy tube placement is controversial and is dependent on the clinical situation. Several studies have been conducted to evaluate the need of prophylactic antibiotic use prior to chest tube placement. The majority of these studies have been limited by heterogeneous population mix and lack power to demonstrate a clinically significant difference. The Eastern Association for the Surgery of Trauma guidelines does not support the use of prophylactic antibiotics [12]. Patients with non-traumatic spontaneous pneumothorax do not require prophylactic antibiotics prior to chest tube insertion. A recent systematic review and meta-analysis of patients with penetrating thoracic trauma demonstrated significant reductions in the risk of empyema (OR 0.28, 0.14–0.57) [13]. This is supported by a meta-analysis by Sanabria, which demonstrated that the use of prophylactic antibiotics in patients with chest trauma decreased the incidence of posttraumatic empyema (RR 0.19, 0.07–0.50) and pneumonia (RR 0.44, 0.27–0.73) [14]. Despite these studies, the question of prophylactic antibiotics remains controversial. Infectious complications of tube thoracostomies can be minimized by ensuring adequate drainage of hemopneumothorax and using appropriate sterile techniques for tube placement.

Tube Selection

Adequate drainage of traumatic hemothoraces is essential in order to prevent retained hemothoraces, complications of additional tube thoracostomy, infection, and trapped lung. The optimal tube size for drainage of pneumo- or hemothoraces is unknown. A recent study by Inaba demonstrated no clinically significant difference between 28 and 32 versus 36 and 40 French chest tube size [15]. A smaller study by Kulvatunyou demonstrated that 14 Fr pigtail catheters could be effectively used to drain hemothoraces in stable trauma patients [16]. This is an area that requires further study before firm recommendations can be made. Patients at risk of a large air leak due to a bronchial-pleural fistula should have a larger bore tube (20–28Fr) inserted, and consideration should be given to multiple tubes being placed for adequate control.

Occult Pneumothorax

Occult pneumothorax is defined as a pneumothorax detected with thoracic or abdominal CT, and not diagnosed on preceding supine anteroposterior chest X-ray. Patients with small occult pneumothoraces in the absence of positive pressure ventilation can be managed safely without tube thoracostomy. The optimal treatment of patients with occult pneumothoraces requiring positive pressure ventilation is unknown. Recent retrospective data suggests that tube thoracostomy may not be required. However, data from two small randomized control trials suggest otherwise [17–20]. This remains an area of controversy, around which there is a need for further study.

Complications and Post-tube Thoracostomy Management

Close observation of patients following chest tube placement is essential to ensure resolution of the initiating reason for tube placement and for monitoring of immediate or delayed complications. Complications of tube thoracostomy include unresolved or re-accumulation of pneumothorax or hemothorax, improper placement (pleural positioning, lung fissure or parenchyma, intra-abdominal), bleeding, organ injury, tube dislodgement, and empyema. Many of these complications can be avoided by appropriate training and rigorous attention to surgical techniques, including consideration of use of prophylactic antibiotics, careful chest X-ray review and landmarking, sterile technique, and a mindful finger sweep of the pleural space before tube introduction, as well as tactile guidance of the tube into the thoracic cavity. Hemothoraces should be monitored with daily chest X-rays to ensure appropriate resolution of the chest drainage. Retained blood in the chest increases the risk of empyema and fibrothorax by as much as 20 % prompting additional drain placement or surgical decortication [21]. Retrospective and randomized control trial data support the use of early (less than 5 days post-injury) video-assisted thoracoscopic surgery (VATS) for evacuation of retained hemothoraces [21–23].

Timing of chest tube removal is dependent on the resolution of the original clinical presentation. Chest tube drainage less than 100 cm^3/day of serosanguinous or serous fluid with complete radiographic improvement of hemo/pneumothorax may prompt tube removal in the absence of positive pressure ventilation. Patients under positive pressure ventilation should avoid having chest tubes removed given the increased risk of recurrent pneumothorax leading to possible tension pneumothorax; however the risks of secondary complications such as infections must also be weighed and balanced. If there is no air leak present, no surgical procedure is anticipated in the upcoming days, high pressures are not required for ventilation, and the patient is being physiologically monitored, and is hemodynamically stable, with an in-house physician, one could consider removal.

Vascular Access

Early establishment of vascular access in patients who are critically ill is essential for both volume expansion and medication delivery. Selection of vascular access sites is dependent on the goals of resuscitation. Large-volume resuscitation can be achieved using large-bore peripheral access. Central access is usually reserved for medication delivery; however large-volume resuscitation can also be achieved depending on the catheter size selected. Large-volume resuscitation is restricted by the size of the intravenous access. The flow is determined by the Hagen-Poiseuille equation, which states

$$Q = \Delta P \times \left(\pi r^4 / 8\mu L\right)$$

where
Q = Flow in L/s
μ = Viscosity in Pa s
P = Pressure in Pascals
r = Radius of the tube in meters
L = Length of the tube in question in meters

Essentially, large bore size and short length are needed to maximize flow. Tables 17.1 and 17.2 outline typical flows seen with catheters.

Table 17.1 Flow characteristics in peripheral vascular catheters

Gauge size	Inside diameter (mm)	Length (mm)	Flow rate (mL/min)
16 (grey)	1.3	30	220
18 (green)	1.0	30	105
		50	60
20 (pink)	0.8	30	60

mm millimeters, *mL/min* milliliters per minute

Table 17.2 Selected characteristics of triple-lumen central venous catheters and intraosseous access

Size (Fr)	Length (cm)	Lumens	Lumen size (Ga)	Flow rate (mL/min)
7	16	Distal	16	57
		Medial	18	30
		Proximal	18	32
7	20	Distal	16	52
		Medial	18	25
		Proximal	18	27
7	30	Distal	16	38
		Medial	18	17
		Proximal	18	18
8.5 (Cordis)	10	Single	8.5 Fr	333
Intraosseous [24]	5	Single	15	165

Fr French, *Ga* Gauge, *cm* centimeters, *mL/min* milliliters per minute

Peripheral Intravenous Access

Peripheral intravenous access is the mainstay of early fluid resuscitation of critically ill patients. Indications for peripheral intravenous access include venous blood sampling, intravenous fluid and medication infusion, blood transfusion, and intravenous contrast administration. Access points include both upper and lower limbs including the long saphenous, cephalic, basilic, and median cubital veins. Contraindications to intravenous access include extremity with significant edema, burns, sclerosis, phlebitis, or thrombosis, and ipsilateral radical mastectomy. Early complications include bruising infiltration, interstitial fluid/medication delivery, thrombophlebitis, infection, nerve damage, and thrombosis [24].

Central Intravenous Access

Central venous catheterization is used to access central veins for medication and fluid delivery and patient monitoring of central venous pressures and right-heart catheterization. A variety of sites can be used including femoral, subclavian, and internal/external jugular veins. Each site has its own set of advantages, disadvantages, and risk of complications outlined in Table 17.3.

Indications for central venous access include emergency venous access; high-volume/flow resuscitation; central venous pressure monitoring; inability to obtain peripheral venous access and repetitive blood sampling; administration of hyperalimentation, caustic agents, or concentrated fluids; hemodialysis or plasmapheresis; and placement of transvenous cardiac pacemakers or pulmonary artery catheters. Contraindications for central venous access include infection over the placement site; distortion of landmarks by trauma or congenital anomalies; coagulopathies, including anticoagulation and thrombolytic therapy; pathologic conditions, including superior vena cava syndrome; current venous thrombosis in the target vessel; prior vessel injury or procedures; morbid obesity; and uncooperative patients. Complications for central venous access are outlined in Table 17.3. Infection rates for internal jugular, subclavian, and femoral central lines are reported as 8.6, 4.0, and 15.3 rate per 1,000 catheter-days, respectively [24]. Thrombosis of internal jugular, subclavian, and femoral central lines are reported as 1.2–3, 0–13, and 8–34 rate per 1,000 catheter-days, respectively [24].

Table 17.3 Central line placement

Site	Advantages	Disadvantages	Complications
Internal jugular	Anatomic landmarks are easy to identify with ultrasound	Difficult to access during emergency airway management	Pneumothorax
			Hemothorax
	Head-of-table access	Risk of carotid artery puncture	Chylothorax
	Can recognize and control bleeding with direct pressure	Patient discomfort	Neck hematoma and tracheal obstruction
	Minimal risk of pneumothorax	Vein prone to collapse with hypovolemia	Endotracheal cuff perforation
	Malposition of catheter placement is rare	Avoid if concern about cerebral perfusion	Tracheal perforation
		Avoid in cervical trauma patients	Brachial plexus injury
			Air embolism
			Cardiac dysrhythmia
			Thrombosis
Subclavian	Good external landmarks	Unable to compress bleeding vessels	Pneumothorax
	Improved patient comfort	Blind procedure	Hemothorax
	Easier to maintain dressings	Experience related success rate	Brachial plexus injury
	Accessible during airway management or patients with C-spine collars	Longer path from skin to vessel	Hematoma
		Catheter malposition	Air embolism
			Cardiac dysrhythmia
			Thrombosis
Femoral	Good external landmarks allowing for rapid access	Limits patient mobilization	Arterial puncture
	Technically easy	Delayed circulation of drugs during CPR	Bowel injury
	Does not interfere with CPR	Difficult to keep site sterile	Retroperitoneal hematoma
	Useful alternative with coagulopathy	Increased risk of iliofemoral thrombosis	Psoas abscess
	Trendelenburg position not required	Not reliable for CVP or central venous gas measurements	Bladder injury
			Air embolism

CPR cardiopulmonary resuscitation, *CVP* central venous pressure, *PA* pulmonary artery

During trauma resuscitation the choice of access site however may be practically more limited. Internal jugular line placement is often the least desirable due to cervical spine collars and spinal precautions. While subclavian access may be attractive, the real estate at the head and torso is often in high demand during resuscitation as often there are five or more team members already trying to access this area for airway management, chest examination, chest tube placement, etc. Therefore often the femoral vein is the first choice for emergent/urgent central access despite the higher long-term infection rates [24]. Added advantages for emergency femoral access include lower short-term complications including zero risk of hemothorax, pneumothorax, and airway compromise from neck hematoma, which could potentially complicate an already unstable patient. This line can be converted to an upper extremity line once the patient is stabilized. Femoral access should be avoided in patients with pelvic or lower extremity injury and patients with known vascular pathology.

An obvious but often forgotten practical consideration when choosing a site for upper extremity lines is in the presence of a known pneumothorax, hemothorax, or chest tube, any upper extremity central line should ideally be placed on the ipsilateral side to avoid creating bilateral chest complications. Utilization of dynamic ultrasound guidance allows access to brachial and basilic veins in the upper extremity. The basilic is not just capable of accepting the largest peripheral lines but also longer central lines which may then terminate in the proximal subclavian vein (peripherally inserted central venous catheters). The utility of such peripherally placed lines is obvious.

A common misconception is the absolute necessity of central venous access for vasopressor infusions. Certainly in the long term a central venous line is a safer mode of delivery for these drugs; however, in the trauma bay or code situation any vasopressor can be run through either a large-bore peripheral line or intraosseous line until central venous access can be established. The main risk is tissue necrosis with extravasation and therefore care should be taken to ensure there is good flow and the peripheral line does not become dislodged. Policies and procedures may vary by institution and care location (trauma bay versus intensive care unit), and we therefore suggest reviewing your local policies and drug monographs.

Intraosseous Access

Intraosseous (IO) access is a technique where a needle is advanced into the bone marrow to achieve an entry point into the systemic venous system. IO route provides a rapid and effective means of administering drugs, fluid, and blood. Blood can also be drawn from an IO device and used for blood gases, electrolyte and hematologic evaluation, and blood cultures [25–27]. This technique is indicated for adult patients in whom attempts at peripheral or central venous access have been unsuccessful. This may include adult patients with burns, trauma, shock, dehydration, or status epilepticus [28]. Multiple sites, including the iliac crest, femur, proximal and distal end of the tibia, radius, clavicle, and calcaneus may be used [29–32]. A wide variety of commercial IO devices are currently available, making the insertion very user friendly. It is important the provider is familiar with local hospital practice and equipment. Detailed description of IO placement is provided elsewhere [33]. IO devices should be avoided in those sites where there is orthopedic or vascular trauma because of the risk of extravasation. Other relative contraindications include cellulitis or burns over the insertion site, patients with known underlying bone disease such as osteogenesis imperfecta, and previous IO attempts on the ipsilateral side. Technical difficulties are the most common complications and are associated with equipment unfamiliarity. Complications of IO devices include malposition resulting in skin and bone trauma, compartment syndrome from unrecognized extravasation, epiphyseal injuries, and fat embolism. Prior to using an IO site 10 cm^3 of normal saline should be flushed through the line. Infusion of fluids through the needle at high rates is sometimes associated with patient discomfort; therefore in awake patients infusing 20–40 mg of 2 % lidocaine without epinephrine will dramatically reduce this discomfort. IO access is meant only for temporary access and should be removed within the first 24 h.

Ultrasound

The use of ultrasound-guided central line placement has become a standard of care. Ultrasound provides a real-time window of a patient's vascular anatomy with the ability to directly visualize placement of central lines into a vessel. Traditional use of anatomical based landmarking for central venous access has resulted in failure and complication rates as high as 19 % and 30 %, respectively [32]. Ultrasound-guided central venous line placement has been demonstrated to significantly decrease the failure rate, complication rate, and number of attempts required for successful access [34–36]. Similarly, ultrasound guidance for peripheral venous line placement has shown marked increase in total and first-pass success in a variety of clinical settings.

A recent randomized, multicenter trial using ultrasound-guided central venous cannulation reported that sonographic guidance had an odds improvement of 53.5 (6.6–440) times higher than landmark-based technique for success of cannulation [37]. The average number of cannulation attempts was also significantly lower in the ultrasound-guided group. The frequency of complications related to line placement is reduced with the use of ultrasound. For internal jugular line placement arterial punctures are reduced from 9.4 to 1.8 %, hematomas 2.2 to 0.4 %, and pneumothorax 0.2 to 0 % [38–40].

In the emergency situation, however (especially when no other access is available), the risk of potential increased complications from landmark-based central line insertion should be weighed against potential time delay from setup for an ultrasound-guided procedure and or lack of an ultrasound being available.

Resuscitative Thoracotomy

A resuscitative thoracotomy (RT) is an emergency procedure used to gain access to the chest in severely injured patients. The decision to perform an RT should be guided by consideration of mechanism of injury and signs of life. The rationale for performing an RT is (1) release of cardiac tamponade, (2) control of intrathoracic hemorrhage, (3) evacuation of air embolism, (4) performance of open cardiac massage, and (5) cross-clamping of the descending thoracic aorta [41, 42]. Given the potential risk involved to healthcare workers the decision to undertake an RT must be made in the context of an anticipated successful clinical outcome, and familiarity of performing the procedure. Trauma patients arriving to the emergency department (ED) pulseless should be assessed for clinical history, cardiac rhythm, and a brief neurologic examination prior to commencement of an RT. Patient management is guided initially by mechanism of injury and downtime. Victims of blunt trauma with no signs of life upon arrival to the ED universally have poor survival rates (<1 %) [42, 43]. RT should not be performed in this population. Patients with penetrating thoracic injury with previously witnessed cardiac activity within 15 min of presenting to a trauma center or unresponsive with hypotension (SBP < 70 mmHg) despite ongoing resuscitation should be considered for an RT. Relative indications for RT include penetrating thoracic injury with traumatic arrest with previously witnessed cardiac activity, and penetrating non-thoracic injury with traumatic arrest with previously witnessed cardiac activity (pre-hospital or in-hospital). Other indications for urgent thoracotomy include (1) chest tube output >1,000 mL, (2) evidence of ongoing bleeding following placement of a tube thoracostomy at a rate of 200–300 mL/h for 4 h, (3) massive chest tube air leak, (4) cardiac

Table 17.4 Operative technique for resuscitative thoracotomy

Surgical step	Description	Equipment
Sterilization of skin	Application of chlorhexidine to the skin surface	Chlorhexidine
	Draping as appropriate	Surgical drapes
Surgical incision	Anterolateral incision at the 4th or 5th intercostal space	#10 Scalpel blade
	Division of the intercostal muscles	Mayo scissors
	Placement of the rib spreader with ratchet mechanism facing downward	Rib spreader
Mobilization of the lung	Divide the inferior pulmonary ligament	Metzenbaum scissors
Bleeding control	Apply digital control or pack the chest with surgical sponges	Surgical sponges
Pericardiotomy	Lift the pericardial sac with forceps and cut pericardium with scissors	Metzenbaum scissors
	Extend incision caudal-to-cephalad to avoid injury to the phrenic nerve	
Aortic cross-clamping	Bluntly dissect surrounding tissue	Vascular clamp
	Identify esophagus	
	Apply temporary vascular clamp to aorta	
Hilar cross-clamping	Identify the pulmonary hilum	Vascular clamp
	Apply temporary vascular clamp	Surgical sponges
Clam-shell exposure	Anterolateral incision across the sternum to the right 4th or 5th intercostal space	#10 Scalpel blade
	Divide the sternum with a Lebsche sternal knife	Lebsche sternal knife
	Reposition rib spreader as appropriate	Rib spreader

tamponade, and (5) air embolism [41–43]. Despite these indications, providers must also consider the patient disposition for definitive surgical repair following a successful RT. Limitations in hospital infrastructure and personnel may prevent successful outcomes. An RT is conducted through anterolateral thoracotomy along the fifth intercostal space on the side of the injury. Although the procedure is not technically difficult, once inside the thoracic cavity, it is imperative that there be a surgical expert present or close by to deal with the next steps of definitive management. Detailed surgical steps of an RT are detailed in Table 17.4 [44].

Outcomes

A clinically successful RT in the setting of blunt trauma is rare (<1 %). Improved outcomes are seen in patients with penetrating (8–10 %) injuries. The greatest survival advantage is an RT performed for stab wounds (18–24 %). Survival following a gunshot wound with an RT is 4–5 % [45].

Contraindications

Contraindications for an RT include blunt injury without witnessed cardiac activity, penetrating trauma without cardiac activity (CPR > 15 min) and no signs of life (pupillary response (in the absence of epinephrine administration), respiratory effort, or motor activity), non-traumatic cardiac arrest, severe head injury, severe multisystem injury, improperly trained team, and insufficient equipment [42, 43].

Volume Expansion

Patients presenting with the need for an RT are often volume depleted and require fluid resuscitation. As such, appropriate IV access is required to achieve administration of crystalloid or blood products. Fluid administration is titrated to achieve end-organ perfusion. The use of vasopressor support should be limited and used only as a temporary measure to support blood pressure in a crashing patient, especially in the setting of pure hemorrhagic shock [46]. The use of vasopressors has been shown to be deleterious [47].

Management

The decision to perform an RT should be guided by the algorithm outline above. Once the decision for an RT is made, OR staff should be put on hold in anticipation of definitive management in the OR. Team dynamics and organization are orchestrated by the TTL in order to maximize patient and healthcare provider safety. As described above each team member should have pre-defined roles within the resuscitation team. Protective equipment should be worn by all team members. The patient-directed goal of RT in the ED should be to temporize thoracic injury and reestablish systemic oxygen delivery. Temporizing measures in the ED should be limited to digital compression of cardiac or vascular injuries, aortic or pulmonary hilar cross-clamping, or packing of chest wall injuries with definitive repair and continued resuscitation done in the controlled confines of the OR. In pre-arrest patients the decision for transfer to a standby OR for definitive management should be considered. This decision is based on the injury patterns of the patient, anticipated clinical course, and availability of an OR and support staff. A recent study by the Western Trauma Association demonstrated improved outcomes when patients were managed in the OR or in the ED with equipment setup similar to the OR [48]. Successful RT requires definitive surgical repair in the OR. Management of cardiac injuries, injuries of the great vessels, lung, tracheobronchial tree, esophagus, and thoracic aortic rupture should be definitively managed in the OR [44, 49]. This should be done by a trained trauma surgeon or cardiothoracic surgeon.

Diagnostic Peritoneal Lavage

Diagnostic peritoneal lavage (DPL) is a diagnostic procedure used to provide information in the evaluation of patients with blunt or penetrating trauma. With the widespread integration of FAST ultrasound (Chap. 21) and improved resolution of computed tomography (CT) (Chap. 24), some believe that DPL has become a lost procedure [50–53]. This has led to a poor understanding of current indications for DPL [54]. Despite the low frequency of use, DPL remains the most sensitive test to identify mesenteric and hollow viscus injury [55].

In the era of modern trauma care DPL may be indicated in the following clinical circumstances [54–57]:

- Hemodynamically unstable patients with suspected multicavitary bleeding but with negative or indeterminate FAST
- Stable patients with anterior abdominal stab wounds with proven peritoneal violation in the absence of peritonitis
- Trauma patients with known, pre-existing ascites

A variety of surgical techniques have been described for performing a DPL. The most commonly used are the open and Seldinger techniques. These methods are described elsewhere [58]. A supraumbilical approach should be considered in patients with pelvic fractures, pre-existing lower midline surgical incisions, or early pregnancy. Decompression of the stomach and bladder is important to prevent iatrogenic injury.

Interpretation of Results

If the initial aspiration of peritoneal fluid yields 5–10 cm^3 of gross blood the test is positive. In the absence of gross blood on the initial aspiration 1 L of normal saline is infused into the peritoneal cavity. The mixed fluid is then sampled. The following is suggestive of a positive test: in the setting of blunt abdominal trauma a red blood cell count (RBC) more than 100,000/cm^3 is considered a positive test; for penetrating trauma, there is no consensus; however for anterior abdominal injuries more than 100,000/cm^3 RBC is considered positive; other positive results include more than 500/cm^3 white blood cell count or the presence of gross or microscopic enteric contents [55–57].

Complications of DPL include catheter misplacement, vascular injury, intra-abdominal or retroperitoneal organ injury, and wound infection.

In summary, DPL remains a useful adjunctive diagnostic test despite widespread use of FAST ultrasound and CT scans. Knowledge of the different diagnostic criteria based on mechanism of injury is required [54].

Conclusions

This chapter provides an integrated approach to emergency critical care procedures including surgical airway management, vascular access, tube thoracostomy, resuscitative thoracotomy, and diagnostic peritoneal lavage. The combination of teamwork, organization, communication, situational awareness, and realization of limitations as well as uncompromising attention to technical detail is essential for successful management of critically ill patients.

Key Points

- The team architecture and dynamic are centered around a TTL whose responsibility is to provide oversight in the management of critically ill patients.
- A generalized approach and knowledge of indications, contraindications, controversies, and common pitfalls of surgical airway management, vascular access, tube thoracostomy, resuscitative thoracotomy, and diagnostic peritoneal lavage is essential for all trauma providers.
- Clear communication is crucial when resuscitating critically ill patients and performing emergency procedures.
- The health and safety of each team member is critical. Personal protective equipment should be worn in all emergency procedures.
- Post-procedure debriefings provide opportunities of learning and evaluation of quality health care delivery.

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Part IV

Specialized Trauma Populations

18 Trauma in the Pediatric Patient

Mahmoud Elbarbary, Betty Jean Hancock, and Melanie I. Morris

Introduction

Pediatric injuries are a significant health care problem and trauma is the leading cause of death in children in the world [1, 2]. It represents a major financial burden as well as emotional trauma for children, parents, and society. The world report on child injury prevention issued by World Health Organization (WHO) and the United Nations Children's Fund (UNICEF) indicates that 2,270 children die every day as a result of an unintentional injury [3]. The report indicates that the burden of injury on children is unequal. Children in poorer countries and those from poorer families in better-off countries are the most vulnerable. More than 95 % of all child injury deaths occur in low-income and middle-income countries [3]. Although the child injury death rate is much lower in high-income countries, injuries still account for about 40 % of all child deaths in these countries. Therefore, it remains important to understand contributing factors, etiologies, and particularities in pediatric trauma to develop better treatment, reduce morbidity and mortality, and implement prevention strategies.

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Pediatric Trauma Particularities

Deaths from unintentional injury peak during the toddler years (ages 1–4) and again during adolescence and young adulthood (ages 15–24). The etiologies of injuries are development and age dependent [4, 5]. The age of a child is predictive for risk and type of injury. Infants are more likely to sustain fatal injuries from suffocation, motor vehicle crashes, drowning, and burns [6]. Toddlers and preschool children are more likely to die from drowning, motor vehicle collisions, fires and burns, and suffocation [6]. Motor-vehicle occupant injury is the most significant mechanism of injury in the school-age child and the adolescents [6, 7]. The previously mentioned WHO report showed similar distribution in many countries [3]. When managing a pediatric trauma patient, one must take into consideration the unique anatomic and physiologic differences between children and adults. Specific anatomic considerations when dealing with the pediatric trauma patients include airway, head, spinal cord/spine, brain, chest, and abdominal particularities. The pediatric physiologic responses to injury have several peculiarities. Patient's compensatory mechanisms are limited. The neonatal circulating total blood volume can be as low as one cup. The total amount of fluid loss required to produce shock is significantly less in children than in adults. That explains why hemorrhagic and hypovolemic shock can occur rapidly in pediatric population. In addition, the capillary hematocrit is only around 30 % of blood hematocrit which means that any drop in child hemoglobin level can dramatically affect the tissue oxygenation. Low hematocrit causes low diastolic pressure. When combined with the tachycardia induced by hypovolemia and anemia, serious deleterious reduction of coronary perfusion pressure occurs that can in fact lead to cardiogenic shock. This is rapidly aggravated by the deleterious effects of the possibly accompanied metabolic acidosis. That may explain the lower threshold for blood transfusion for neonates and infants below 4 months compared to older pediatric patients or adults [8, 9].

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Airway Considerations

More specifically the small oral cavities and relatively large tongues and tonsils predispose to airway obstruction and the relatively large occiput naturally flexes the neck in the supine position. The larynx is more cephalad and anterior in the neck [10] making visualization during intubation more challenging and a short trachea creates a higher risk for tube dislodgement and/or mainstem intubations [11].

Head and Spinal Trauma

Head trauma following blunt injury is the leading cause of mortality related to a disproportionately large head relative to body size in children under the age of 8. Before skull suture closure, infants may have larger subarachnoid spaces and thus tolerate larger intracranial hematomas better than adults. However after sutures are closed an epidural has much less space to expand than in the geriatric head that may have a degree of atrophy. Infants may still sustain significant parenchymal injury as the infant brain is less myelinated and the cranium is thinner and less protective [12]. Increased flexibility, which allows the spine to stretch, puts children at increased risk of "spinal cord injury without radiographic abnormalities" (SCIWORA) [13].

Torso Trauma

Children have a more compliant chest wall. As a result, rib fractures are less common, pulmonary parenchymal injuries are more likely, the liver and spleen are less protected, and, because of their mobile mediastinal structures, pediatric patients are more likely to develop tension pneumothoraces [9]. Differences between adult and pediatric physiology are critical in understanding the pediatric trauma patient. Normal vital signs vary with age and, in general, the heart and respiratory rates are higher in children and the blood pressure is lower (Tables 18.1 and 18.2). Hypothermia is a major risk in children due to their large body surface area, which may lead to a worsening metabolic acidosis and exerts a negative inotropic effect on the heart [14]. The most common cause of arrest is hypoxia, because of limited functional residual capacity and increased oxygen utilization relative to adults. They are also at a greater risk for iatrogenic barotrauma from aggressive ventilation as they have smaller tidal volumes and less pulmonary compliance due to underdeveloped elastic components. Physiologic reserves can make usual signs of shock such as hypotension less apparent until later stages. Although tachycardia and poor skin perfusion are initial signs, prompt management is essential prior to the hypotension of uncompensated shock is found.

Table 18.1 Pediatric normal values: heart rate (HR) and respiratory rate (RR) at rest

Age (year)	HR/min	RR/min
Newborn	100–180	30–60
0.5	80–160	25–40
1–5	80–130	20–30
6	75–115	18–25
8	70–110	18–25
10	70–110	15–20
12	F 70–110, M 65–105	12–20
14	F 65–105, M 60–100	12–20
16	F 60–100, M 55–95	12–20
18	F 55–95, M 50–90	12–20

Table 18.2 Pediatric normal values: blood pressure (BP) at rest

	BP (at rest) 90th percentile (systolic/diastolic)	
Age (year)	F	M
Newborn	76/68	87/68
0.5	106/65	105/66
1	105/67	105/69
2	105/69	106/68
4	107/69	108/69
6	111/70	111/70
8	114/72	114/73
10	117/75	117/75
12	122/78	121/77
14	125/81	126/78
16	127/81	131/81
18	127/80	136/84

Psychosocial Considerations

The emotional impact on children, parents, and society cannot be neglected. The initial evaluation and management of children in the trauma setting can often be traumatizing to both the staff and parents. Proper counseling, debriefing, and post-hospital care are essential when addressing the pediatric trauma patient. It is equally important to consider prevention strategies and effective injury prevention and control require a comprehensive and integrated system that can monitor and collect essential data as the ongoing data collection systems recommended by WHO [15].

Pediatric Management Challenges

The previously mentioned peculiarities of the pediatric trauma patient may lead to challenges in executing appropriate management in a timely fashion in this special population. Establishing initial differential diagnoses of the patient's injuries depends to a great degree on an appropriate history and physical examination as well as pertinent laboratory and radiologic investigations. Obtaining an accurate and comprehensive history from pediatric patients can be a challenge due to patients' inability to communicate or due to events that are unwitnessed. Collateral history from parents, when available, can be impaired by the stress and emotional impact of the situation on the parents [16–18]. Certain signs may raise the suspicion of child abuse [19, 20]; subsequently a new set of rules should be considered in obtaining the history as recently recommended by the American Academy of Pediatrics [21] that may include interviewing and examining the child without the parents' presence. The physical exam of a pediatric trauma patient can vary significantly in reliability based on the experience of the examiner. That involves simple tasks such as assessing volume status [22] or even measuring the temperature [23]. For instance, reading chest X-ray in emergency room for children with suspected pneumonia is reported to have high degree of intra-observer variability [24]. More advanced investigation can be limited in children due to the invasive nature of the test, the need for sedation, the increased risk of radiation exposure, or the inability to get consent in a short time. Because of concerns over ionizing radiation in this age group ultrasound carries a particular value, as will be explained later. Reducing diagnostic errors in pediatric emergency department can be achieved by adopting some of the key principles such as the ones suggested by Croskerry and others [25–27]. Croskerry, who is specialized in Emergency Medicine, hypothesized that the diagnostic process in ED follows the so-called dual process theory. The theory suggests that two basic modes of thinking are in action to reach a diagnosis. Type 1 processes are fast, reflexive, and intuitive, and may operate at a subconscious level. In contrast, Type 2 processes are analytic, slow, and deliberate that require focused attention. Using checklists [28] with better utilization of system 2 (Table 18.3) and de-biasing and disengagement of the intuitive mode (Table 18.4) are among the key concepts [29] to avoid diagnostic errors in the ED and in decision making in general.

Table 18.3 Hierarchical de-biasing strategies

Universal	Critical thinking training
	Dual process theory training
	Cognitive/affective bias training
Generic	Structured data acquisition
	Get more information
	Be more skeptical
	Slow down/reflection
	Rule out worst-case scenario (ROWS)
	Consider the opposite
Specific	Bias inoculation strategies
	Re-biasing strategy
	Specific forcing functions
	Stopping rules
	Checklists

Croskerry [28]

Table 18.4 Enhancement of system 2

Reflective, careful thinking
Evidence of critical, analytical, skeptical, and disciplined thought
Willingness to look beyond the obvious
Seeks out and considers alternate explanations
Looks for counter evidence
Absence of obvious cognitive or affective bias, stereotyping
Sound logical reasoning
Intellectual honesty
Evidence of critical thinking in analysis of clinical scenarios
Ability to distinguish between weak and strong evidence

Croskerry [28]

Different types of pediatric shock require fast diagnosis and management. Obstructive shock can be due to severe pulmonary hypertension that may occur as a response surge of inflammatory mediators typically in sepsis, massive blood transfusion, severe hypoxia, or acute lung injury. Pulmonary vasodilators should be considered in these cases. Common causes of obstructive shock can be diagnosed by bedside focused ECHO, particularly pericardial tamponade. The distributive shock due to sepsis progresses rapidly in pediatric patients, usually with peripheral vasoconstriction and poor perfusion and far less common (compared to adults) with peripheral vasodilation, or the so-called warm sepsis [30–32]. Therefore, the use of vasodilators (e.g., phentolamine) with inotropes (e.g., epinephrine) or milrinone may constitute a consideration in these cases [33]. Appropriate and prompt correction of glucose (hypoglycemia), acidosis (hydrogen ion abnormalities), and hypoxia is considered among the top "5 Hs" priorities in shocked/arrested child [34]. Calcium correction is particularly important in the pediatric population. In goal-directed therapy of pediatric shock, care should be given to calcium that interacts with many physiological functions particularly myocardial contraction and inotropy [35, 36]. Ca^{2+} facilitates both systolic contraction (inotropy) and diastolic relaxation (lusitropy). Depletion of Ca^{2+} stores, impaired uptake of Ca^{2+} by the sarcoplasmic reticulum (SR), or impairment of the Ca^{2+}-regulating proteins, including SR-Ca^{2+}-ATPase, sarcoplasmic-endoplasmic reticulum Ca^{2+} (SERCA), and phospholamban, can contribute to rapid deterioration of cardiac contraction and thus aggravate the shock state. Treatment of acidosis and other metabolic abnormalities require rapid correct diagnosis that can be facilitated by following a few rules in the interpretation of the blood gas. Table 18.5 provides ten rules of thumb for such conditions and can be used as a pocket card and is available as smartphone image for quick reference. As in adults, multiple doses of etomidate should be used with caution in children with shock conditions because of its potential effects on the hypothalamic–pituitary–adrenal axis [37].

Table 18.5 Ten rules for acid/base balance interpretation

Respiratory acidosis/alkalosis (pH and PCO_2 opposite direction)		
Rule 1	The rule of (1–4 and 2–5)	
	Respiratory acidosis (1–4)	Each rise of PCO_2 by 10 mmHg will be compensated by increase of bicarb by 1 in acute and 4 in chronic
	Respiratory alkalosis (2–5)	Each drop of PCO_2 by 10 mmHg will be compensated by drop of bicarb by 2 in acute and 5 in chronic
Rule 2:	Each acute change Δ of PCO_2 by 10 mmHg will Δ pH by 0.08	
Metabolic alkalosis (pH and PCO_2 same direction)		
Rule 3	$PCO_2 = 0.9 \times HCO_3 + 15$	
Rule 4	$HCO_3 + 15$ = last 2 digits of pH (7.*xy*)	
Rule 5	Metabolic alkalosis can be	
Type	**Chloride resistant**	**Chloride resistant**
	Urine Cl < 10 mmol/L	Urine Cl > 20 mmol/L
Causes	**V**olume depletion	K or Kg depletion
	Vomiting	High mineralocorticoids (aldosterone)
	Villous adenoma	High glucocorticoid (cortisol)
	Diuretics	Excess alkali (bicarbonate-citrate)
	Drugs	Drugs (antacid-effervescent)
Treatment	Treat the VVVDD	Correct K and Mg
	Normal saline (especially if chloride is low)	Treat the cause
		Drugs
		Acetazolamide or ammonium chloride
		or hydrochloric acid
Metabolic acidosis (pH and PCO_2 same direction)		
Rule 6		
(**Rule 6.1**)	Anion gap (AG) = Na − (CI + bicarb)	
	Normal = 12, AG > 19 then it is primary metabolic acidosis	
(**Rule 6.2**)	gap/gap ratio = Δ AG: Δ,bicarb = (AG-12}:(24-bicarb)	
	If it is =1 then high AG acidosis	
	If it is <1 then high AG + normal AG acidosis	
	If it is >1 then mixed metabolic acidosis + alkalosis	
(**Rule 6.3**)	Metabolic acidosis can be either	
(a) High AG acidosis	**(b) Normal AG acidosis**	**(c) Pseudo norm AG acidosis**
Added acid	*Loss of alkali*	*False low AG*
Lactic acid	Drainage (biliary/pancreatic)	Low albumin
Uric acid	Dilution	Paraprotiens
Acetic acid	Diamox	Lipids
Ketoacid	Diuretics	High Ca-High Mg
Amino acid	Disease	Polymyxin B
Salicylic acid	(Addison/renal tubular acidosis)	Lithium poisoning
Rule 7	Rule of 7 each drop of pH by 0.1, the PCO_2 will drop by 7 mmHg to compensate	
So if	*pH*	*PCO_2*
	7.40	35
	7.30	28
	7.20	21
	7.10	14
Rule 8	Any Δ in pH by 0.01 (not due to PCO_2) is due to base Δ by 0.67	
Rule 9	Total body bicarb deficit = base deficit × body Wt. × 0.3	
Rule 10	(Interpretation steps)	
	Identify the primary abnormality	
	See PCO_2 and pH directions	
	Calculate expected compensation and compare to the actual value	
	Look for the mixed abnormality	
	Integrate with clinical data	
	Remember, the body NEVER overcompensates	

"Critical" Ultrasound in the Pediatric Patient

The published reports [38–44] about the FAST (focused assessment with sonography in trauma) exam in children carried conflicting results but in general indicate low sensitivity. The physiological and anatomical differences that are explained earlier in this chapter may explain the difference in the FAST utility in children versus adults and may also explain the relatively less uptake of FAST in pediatric population. Despite the fact that a negative FAST exam does not have a useful rule-out value, a positive FAST exam is still very useful in stratifying the management of pediatric trauma cases.

Beyond the ultrasound role in the initial detection of abdominal fluid by FAST, ultrasound (**US**) recently gained an increasing role in stabilization of shocked patient in the ED. A new philosophy of US imaging recently emerged which is the "***problem-based critical***" ultrasound. This is a paradigm shift from being an organ-based, systematic, comprehensive diagnostic exam to a new concept of ***problem-based***, goal-directed, focused multi-organ, time-dependent exam done by the treating physician. Based on this concept, the US exam is not just done for detection of fluid collection or for an organ or region (e.g., US for abdomen or chest) but rather done to enhance the management of a problem (US for hypotension, US for hypoxia, US for sepsis, etc.). Certain problem-based US exams can involve scanning of multiple organs to enhance the management of a certain patient's problem. The US within this concept is not considered just as a diagnostic tool but rather as an integral part of ED management that involves diagnosis, tailored treatment, monitoring effects, goal-directed therapy, ruling out possible complications, and of course guiding most of the pediatric ED procedures [45]. If we consider the example of "ultrasound for hypotension," a process of scanning of three organs (heart, inferior vena cava (IVC), and lung) will generate a "***sonodymanic***" pattern to enhance the management of hypotension as follows [46]:

1. ***Gross evaluation of right and left ventricular functions***. This is usually done without detailed quantitative measurements but rather done by global qualitative exam of both right ventricle (RV) and left ventricle (LV). This quick exam also rules out/in any pericardial collection.
2. ***Vena cava analysis***. A small IVC with spontaneous collapse suggests hypovolemia (*flat IVC*) that is usually fluid responsive. A distended IVC (*fat IVC*) will be fluid nonresponsive and may suggest hypervolemia, pulmonary hypertension, or tamponade. When interpreted with pertinent echocardiographic signs (step 1), then the diagnosis can be immediately established [46]. In addition to IVC, also superior vena cava and aortic flow have been used to assess fluid responsiveness in children and adults [46]. However, because of the variability in pediatric body size and growth, absolute values are not helpful and only relative indices [47–49] such as the ones listed in Table 18.6 may have potential application in the pediatric patient. This however remains an area waiting for validation by better quality studies in the pediatric trauma population. In the presence of a fixed and distended IVC, a small and hyperkinetic right ventricle is suggestive of tamponade (especially if combined with rapid accumulation of pericardial fluid) with possible right ventricle or right atrial collapse. On the other hand, a dilated and hypokinetic right ventricle may signify pulmonary hypertension.
3. ***Assessment of the lung***. A profile of lung ultrasound is characterized by multiple horizontal artifacts (A-lines) which are findings of well-aerated normal lung. With the loss of air in the lung and development of different lung pathologies, several artifacts and new ultrasound features may appear (as summarized in Table 18.7 and Figs. 18.1, 18.2, 18.3, and 18.4), particularly the appearance of

Table 18.6 Relative indices for ultrasound assessment of fluid responsiveness

Name	Symbol	Equation	Cut value[a] (%)	*R#*
IVC collapsibility index	Δ IVC	$100 \times \frac{\text{IVCins} - \text{IVCexp}}{\text{IVCins}}$	>18[a]	47
SVC collapsibility index	Δ SVC	$100 \times \frac{\text{SVCexp} - \text{SVCinsp}}{\text{SVCexp}}$	>36	48
Ao velocity index	Δ AoV	$100 \times \frac{\text{Vpeakmax} - \text{Vpeakmin}}{(\text{Vpeakmax} + \text{Vpeakmin})/2}$	>12	49

IVC inferior vena cava, *SVC* superior vena cava, *Ao* aortic, *V* velocity, Δ delta or change, *Ins* inspiration, *exp* expiration, *peak* peak velocity, *max* maximum, *min* minimum, *R* reference

[a]Patient likely to be fluid responder if the index is above the cut value. If ΔIVC>50 % then CVP is estimated to be <10 cmH_2O

Table 18.7 Key points in lung ultrasound

Choosing the appropriate probe
Lower frequency (**curvilinear probe**): better penetration, worse resolution for consolidation or congestion. Use 5 MHz
Higher frequency (**flat probe**): worse penetration, better resolution for nearby lesions like effusion or pneumothorax. Use linear or curvilinear probe 8 MHz
Probe marker
Toward the head: marker @ 12 o'clock (vertical scan)
Toward the right: marker @ 9 o'clock or in between ribs (oblique scan)
Normal lung
By 2D: Pleural sliding and **A-lines**
M mode: **Seashore sign**: 2 distinct regions, one is granular (moving) and the other with straight lines (non-moving region)
Abnormal lung
PLAPS: *Posterior and/or lateral alveolar and/or pleural syndrome. Detection of consolidation or effusion or both at the posterior wall*
Shred sign: A tissue-like mass abutting the pleural line has a shredded lower border
Lung pulse: pleural line vibrations in rhythm with the heart rate
Stratosphere/barcode sign: M-mode pattern composed of horizontal lines in an intercostal view (characteristic of pneumothorax)
Quad sign: Quad shaped by the four borders of a pleural effusion, when seen in intercostal approach: pleural line, shadows of bones, and the deep lower border
Sinusoid Sign: by M-mode **curve at the level of a pleural effusion**
Pleural effusion: *by 2D*: Quad sign *M mode* sinosoidal sign
Collapse: by 2D: B-lines and air bronchogram
Consolidation: by 2D: B-lines and shred sign
Pneumothorax scan
By 2D: no pleural sliding, no B-lines
M mode: **barcode sign**—one single non-moving region with straight lines
Lung point is a point above which there is barcode sign and below which is normal seashore sign
Airway US
Vocal cords: Probe Marker @ 3 o'clock above cricoid cart
Trachea: Probe Marker @ 12 o'clock (train sign)
Trachea for ETT size estimation Probe Marker @ 3 o'clock

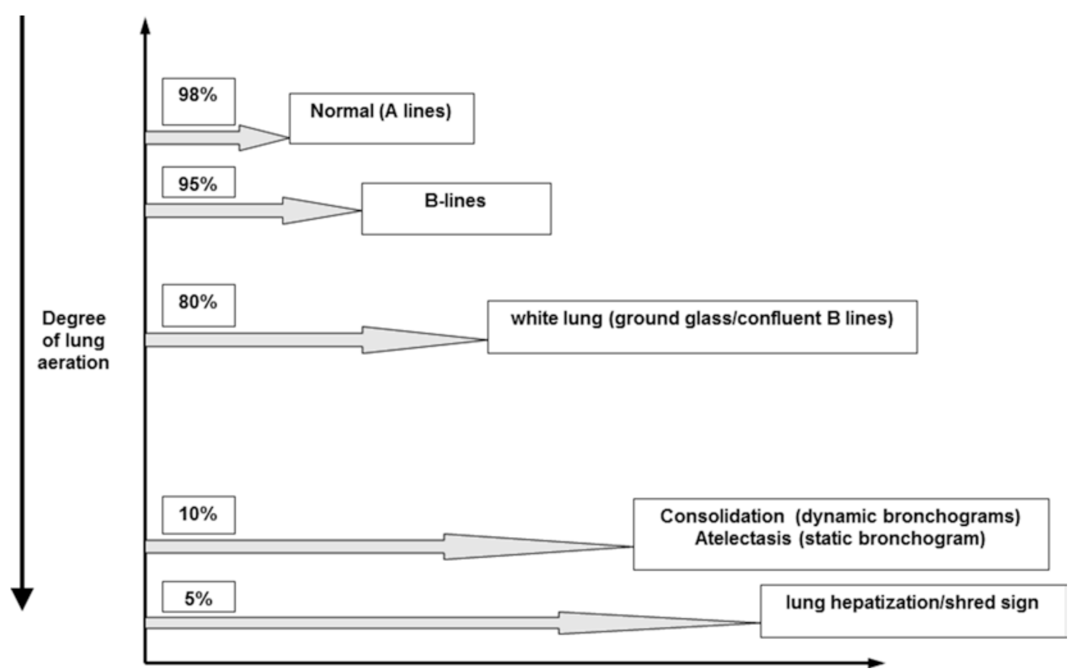

Fig. 18.1 The relation between degree of lung aeration and ultrasound findings

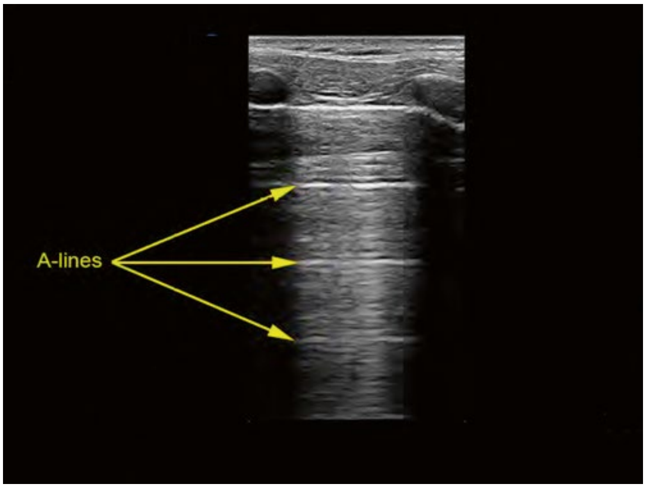

Fig. 18.2 Normal horizontal A-lines (reverberation from pleural line)

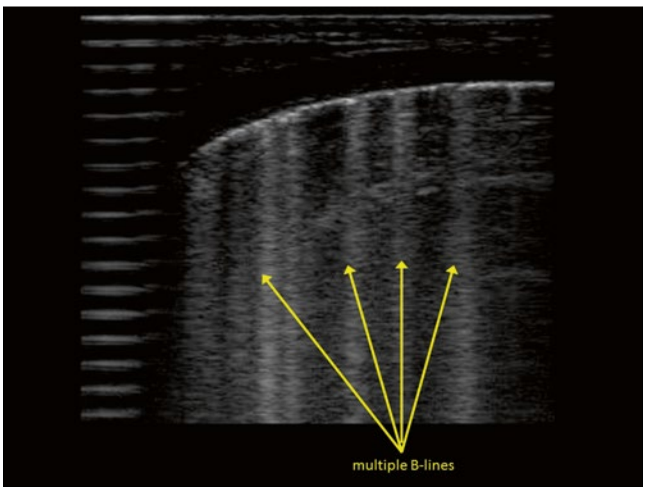

Fig. 18.3 Abnormal vertical B-lines

Fig. 18.4 Abnormal marked loss of lung aeration resulting in whitening of the whole screen by multiple confluent B-lines. In case of confluent B-lines that whiten only part of the screen (black and white lung), the number of B-lines can be estimated by dividing the proportion of whitening/10 (if 70 % white then estimated B line is 7)

Table 18.8 Lung scan difference between cardiogenic versus noncardiogenic pulmonary edema [50]

Cardiogenic edema	Noncardiogenic edema
B profile	B profile
Homogeneous distribution	Heterogenous distribution
Normal sliding	Reduced sliding
Normal pleural thickness	Thickened irregular pleura
Often pleural effusions	Peripheral consolidations
Normal vascularization	Enhanced vascularization

abnormal multiple vertical lines (B-lines). A hypokinetic LV and a B-line profile by lung ultrasound in a hypotensive pediatric patient with low oxygen saturation are suggestive of cardiogenic pulmonary edema, indicating thus the administration of diuretics and inotropes. Once this is suspected, fluid administration in such cases should be extremely cautious. That is part of "ultrasound for hypoxia" that includes the lung and heart exam. The presence of an A-line profile in lung ultrasound usually rules out pulmonary edema. In addition to heart assessment, simple ultrasound signs (Table 18.8) for the lung can differentiate cardiogenic from non-cardiogenic pulmonary edema [50]. Some reports claim the ability of ultrasound to differentiate between bacterial and viral pneumonia in pediatric ED with using the six-zone lung scanning technique which is somewhat different from the adult approach [51].

This ***problem-based*** ultrasound concept can be summarized in an algorithm. Many proposed algorithms (such as BLUE or FALL protocols) were published and claimed suitable for pediatric application/modification [52]. This too requires further validation. Nevertheless, ultrasound is increasingly used in many situations such as shock, sepsis, titrating fluids/vasoactive drugs, managing hypoxia, optimizing mechanical ventilation, assessing cerebral perfusion by transcranial Doppler (TCD), managing abdominal hypertension, and facilitating goal-directed therapy [53]. Few evidence-based guidelines were published in this regards and more are under consideration for publication soon [50, 54–57]. Point-of-care ultrasound and its potential applications in trauma will be discussed further in Chaps. 21 and 22.

Pediatric Trauma Team Composition and Dynamics

The management and outcomes of trauma victims, both adult and pediatric, changed substantially with the development and promulgation of the Advance Trauma Life Support (ATLS®) training course [58]. The approach to the patient and knowledge content is well established at this point with modifications incorporating evidence-based practice. The current focus is on quality care and improving outcomes [59, 60].

To this extent, the American College of Surgeons has developed TQIP and PQIP (Trauma and Pediatric extensions, respectively, of the National Surgical Quality Improvement Program, NSQIP) to provide accurate and concurrent data that can be effectively analyzed to determine factors that will improve patient care [61]. At the heart of quality improvement and optimization of outcomes in the pediatric trauma victim is effective and successful resuscitation. This begins in the pre-hospital setting and carries on through the initial assessment and management of the pediatric trauma patient. As outlined in previous chapters, it has long been recognized that a well-organized and integrated trauma team is critical in achieving optimal resuscitation outcomes. The composition of the pediatric trauma team is variable. It usually involves an average of six people including physicians, nurses, respiratory therapists, and trainees. Pediatric resuscitations have been described as the "perfect storm" where critical and life-threatening injuries must be diagnosed and appropriately treated in a timely fashion in a setting that is adversely affected by many factors such as a highly stressful environment, emotional challenges for families and staff, variable expertise and experience of caregivers, and the dynamics of the resuscitation team. There are controversies [62, 63] regarding reports of potential improving of outcome when pediatric trauma victims are managed in pediatric trauma center (PTC) compared to adult trauma center (ATC) or ATC-AQ (added-qualifications for pediatrics). In addition, due to the significant shortage of PTC/ATC-AQ, a clear disparity in access of care is reported [64–66].

As discussed in Part 1 of this book, crisis resource management (CRM) involves principles of interpersonal interactions and behaviors that contribute to optimal team functioning during crises. The principles of CRM were reviewed by Cheng et al. [67]. CRM as applied to pediatric trauma resuscitation involves all of the key principles including leadership and followership, communication, teamwork, resource use, and situational awareness. CRM is a learned skill which can be effectively acquired through simulation-based training [67, 68]. Health care providers can develop and perfect their skills of leadership, communication, and teamwork in a safe and stress-free environment without risk to patients. Team performance can be assessed and reviewed in the debriefing, highlighting performance gaps and facilitating discussion and resolution of identified deficiencies. The recent development of trauma team development courses such as Simulated Trauma and Resuscitation Team Training (STARTT) [68] and Trauma Resuscitation in Kids (TRIK) [69] will further the preparation, training, and performance of the trauma team facilitating optimal outcomes for pediatric trauma patients.

The decision to terminate resuscitation in the traumatized child continues to be a difficult one. There is a significant paucity of research in this area. Nevertheless it is an important issue to address as prolonged attempts to resuscitate a terminally injured child are exhausting both physically and emotionally for all members of the trauma team as well as the parents. Capizzani [70] and Murphy [71] have determined that children requiring CPR in the field and arriving in the Emergency Department with ongoing CPR (>15 min), nonreactive pupils, absent pulse, and unorganized ECG will not survive their injuries and that termination and/or withholding resuscitation in children who meet these criteria is reasonable. Further studies are required to establish termination of care evidence-based guidelines. Recently [57], it was suggested to use ultrasound during CPR for possible enhancement of these decisions and better detection and management of some condition related to pulseless electrical activity (PEA) and asystole.

The value of other resources in the initial care of the traumatized child is not well defined. Certainly, issues of child abuse requiring the input of social work and child and family services are recognized but the necessity of their presence in the acute phase of resuscitation is not known. Ethical issues related to substituted judgment, surrogate decision making, conflict of interest, and child abuse are well explained elsewhere [72] and the adherence to these published guidelines is imperative. The need for resources to support decision making on difficult ethical issues in the resuscitation of the traumatized child requires more research. In addition there is a need to investigate the various models of shared decision making (SDM) in pediatric emergency field [73]. Table 18.9 [74] shows the four models that constitute the spectrum of the patients/parents role in decision making. Moving from one end to the other end of this spectrum is frequently required as cultural factors play important role in determining the most suitable model of SDM.

Table 18.9 The four-models spectrum of shared decision making [74]

	Parental	Clinician-as-perfect agent	Shared decision making	Informed
Choice talk	Implicit	Clinician	Team	Patient/parents
Option talk	Informed consent	Clinician ⟶		Patient/parents
Deliberation	Clinician	Clinician	Joint	Patient/parents
Decision talk	Clinician orders	Clinician recommends	Consensus	Patient/parents requests
Consistent with EBM principles	No	Yes	Yes	Yes

Conclusions

Pediatric trauma remains a significant burden on health care resources. The impact both physically and emotionally on pediatric patients, their parents, and families and on health care providers can be profound and long lasting. However, careful attention to the peculiarities of pediatric physiology and adherence to standardized ATLS guidelines can help improve outcome and decrease the significant long-term morbidities associated with pediatric trauma.

Key Points

- A pediatric trauma team is composed of highly skilled, multidisciplinary professionals with effective communication and harmony.
- Prompt corrections of glucose, calcium, hemoglobin, and pH abnormalities are vital in pediatric trauma management.
- Trauma due to suspected child abuse has specific guidelines that should be followed.
- Simulated courses focusing on trauma in pediatrics and "CRM" are strongly recommended to improve the quality of training and care.
- While guidelines addressing ethical challenges related to child abuse and substituted judgment are available, there are clear needs for more work related to cessation of pediatric CPR and pediatric shared decision-making models.

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Trauma in Pregnancy

19

Lua R. Eiriksson and Paul T. Engels

Introduction

Trauma is the leading cause of maternal death in pregnancy [1]. It is reported that 50 % of maternal deaths in the USA are attributable to trauma, with over one million deaths occurring per year worldwide [1, 2]. Overall, 6–7 % of pregnancies are complicated by trauma [2, 3], with 0.4 % of all pregnant patients requiring hospitalization for the treatment of traumatic injuries [4]. Over 50 % of injuries occur during the third trimester [5, 6]. The most common mechanisms of injury are motor vehicle collisions [7–9], interpersonal violence [10], and falls [3]. Blunt trauma (80 %) is much more common than penetrating trauma (20 %) [3, 6, 10] with the latter resulting in perinatal mortality rates of 40–70 % [11, 12]. Leading mechanisms of fetal death are motor vehicle collisions (82 %), firearm injuries (6 %), and falls (3 %), with 11 % of cases involving concurrent maternal death [9]. The underlying primary causes of fetal death are maternal shock, maternal death, and placental abruption [8], while the leading causes of maternal death are head injury and hemorrhagic shock [13, 14]. Obstetrical complications resulting from maternal trauma include premature rupture of membranes, preterm labor, placental abruption, feto-maternal hemorrhage, uterine rupture, and fetal and/or fetal-maternal death [3, 5, 15].

The management of the pregnant trauma patient may be complicated by delayed diagnoses of shock or hemorrhage due to minimal changes in vital signs secondary to physiologic changes of pregnancy as well as challenges in the concurrent assessment of both the fetus and the mother. The prevailing principle is that fetal well-being is dependent on maternal status, such that optimal resuscitation of the mother will typically result in optimal resuscitation of the fetus, with consideration given to obstetrical complications that can compromise both mother and fetus.

Physiologic Changes of Pregnancy

Multiple organ systems undergo adaptation during pregnancy. The uterus itself, as it expands with the growing fetus, rises out of the protection of the bony pelvis at the end of the first trimester. During the second trimester the uterus is considered to be an abdominal organ; however the fetus continues to be protected by a relatively large volume of amniotic fluid. It is during the third trimester when the now thin-walled uterus is at greatest risk of penetration, rupture, and premature rupture of membranes [16]. The inelasticity of the placenta in comparison to the elastic uterus increases the risk of abruption when shearing forces are applied [17] and even cases of apparent minor blunt abdominal trauma may result in fetal compromise or death [5]. The uterus and placenta receive 20 % of the cardiac output at this stage, highlighting the urgency for assessment of the uterus during the primary survey. Due to the size and weight of the uterus, placement in the supine position results in compression of the inferior vena cava (IVC) and aorta, thereby negatively impacting cardiac output. Positioning in the left lateral decubitus position (log-rolled 4–6 in. or 15°) or manually displacing the uterus will minimize iatrogenic hypotension and improve cardiac output [18, 19] while also improving fetal oxygenation [20]. This can be done while maintaining spine precautions.

A hypervolemic and hyperdynamic state is achieved during pregnancy to meet the metabolic demands of the mother and fetus. Total blood volume increases by up to 50 % during pregnancy, with a greater increase in plasma volume compared to red cell mass, resulting in a dilutional anemia [13].

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Cardiac output increases due to an increase in blood volume and a decrease in uterine and placental vascular resistance. While the placental vasculature is maximally dilated to facilitate fetal oxygenation, it is highly responsive to catecholamines, such that a stress response in the mother may result in diversion of blood from the uterus [16]. As such, blood pressure support with administration of intravenous fluids and blood products is preferred over the use of vasopressors. Maternal tidal volume and minute ventilation are increased, thought to be secondary to increased progesterone levels, with resultant hypocapnea. Elevation of the diaphragm contributes to a decreased residual volume and should be considered during placement of thoracostomy tubes in later pregnancy (where tube placement may be more appropriate in the fourth rather than fifth interspace). Penetrating injuries below the fourth intercostal space anteriorly or the tip of the scapula posteriorly may result in intra-abdominal injuries. Attention to respiratory status in the pregnant patient requires recognition of the increased oxygen demands placed by the fetus, early recognition of ventilatory failure despite apparent normal $PaCO_2$ values, and a high-risk airway secondary to upper airway edema, increased intra-abdominal pressures, and delayed gastric emptying [16]. Supplemental oxygen should be administered to all pregnant trauma patients to maintain an $SPO_2 > 95$ % or $PaO_2 > 70$ mmHg and consideration given to early placement of a decompressive nasogastric tube to avoid aspiration. Because of increased upper airway edema, a tracheal tube of 0.5–1 mm diameter narrower than a nonpregnant woman of similar size should be used with preparation and backup for a difficult airway [21]. Widening of the symphysis pubis (by 4–8 mm) [22] and sacroiliac joints may impede interpretation of pelvic radiographs. Due to pituitary enlargement, maternal hypovolemia may result in pituitary insufficiency secondary to pituitary necrosis in the setting of maternal shock. A summary of anatomic, physiologic, and laboratory value changes during pregnancy are presented in Table 19.1.

Table 19.1 Anatomic, physiologic, and laboratory value changes during pregnancy

Parameter	Change in pregnancy
Heart rate	Baseline rate increased by 15 bpm
Blood pressure (systolic and diastolic)	Nadir of 15 mmHg below baseline by the end of the second trimester
Cardiac output	Increased by 1–1.5 L per minute over baseline
Total blood volume	Increased by 50 % above normal
Red blood cell mass	Lesser increase compared to plasma volume resulting in dilutional anemia (lower hematocrit)
Respiration	Increased tidal volume and minute ventilation, with resultant hypocapnea
Lung volumes	Decreased residual volume (elevation of diaphragm)
Gastrointestinal motility	Delayed gastric emptying
Gastrointestinal anatomy	Displacement of bowel into upper abdomen
Musculoskeletal	Widening of symphysis pubis and sacroiliac joints
Fibrinogen	Increased (normal fibrinogen may hail the development of disseminated intravascular coagulation)
Pseudocholinesterase levels	Decreased—consider lower dose of succinylcholine during rapid sequence induction
Hematocrit	32–42 %
White blood cell count	5,000–12,000/μL
Arterial pH	7.40–7.45
Bicarbonate	17–22 mEq/L
$PaCO_2$	25–30 mmHg
Fibrinogen	>3.79 g/L (3rd trimester)

Shock in the Pregnant Patient

Due to the physiologic increase in intravascular volume, hemorrhage may initially be well compensated for in the pregnant trauma patient. It is typically only after significant blood loss that tachycardia and hypotension are encountered. At that point, however, catecholamine-induced maternal shunting of blood away from the uterus and placental vasculature will have deprived the fetus of vital perfusion resulting in compromise. Maternal shock is associated with an 80 % fetal mortality rate [23]. Abnormal fetal lie (oblique or transverse), easy palpation of fetal parts, and/or inability to palpate the uterine fundus may suggest uterine rupture, while placental abruption is associated with vaginal bleeding, uterine tetany, and severe abdominal pain. Unfortunately, these clues to suggest obstetrical causes of hemorrhage are not sufficiently sensitive (e.g., vaginal bleeding is absent in 30 % of cases of placental abruption). An additional vital sign is therefore required in the assessment of shock in the pregnant trauma patient: the fetal heart rate (see Fetal Monitoring). Early fetal assessment with frequent intermittent or continuous fetal monitoring should be performed during maternal stabilization, as fetal heart rate changes may be the first indicators of maternal hypovolemia and impending shock. When using this approach, not only will resuscitation of the mother be improved, but the risk of fetal complications, including fetal demise, will be decreased.

Distinct Aspects of the Pregnant Trauma Patient

While the management of thoracic and abdominal injuries during pregnancy differs little from the nonpregnant state, there are certain considerations unique to the pregnant trauma patient. All female trauma patients should be stratified as either potentially pregnant, pregnant at less than 23-weeks gestation, pregnant at greater than 23-weeks gestation, or peri-mortem. Fetal viability is achieved at approximately 23-weeks gestation, at which time maternal resuscitation and fetal assessment should take place concurrently. Gestational age (GA) and the estimated date of delivery (EDD) —or "due date"—is determined using the date of the last normal menstrual period (LMP) (Naegele's rule: EDD = LMP − 3 months + 7 days) or a "dating" ultrasound performed at 8–12-weeks gestation [24]. In order to err on the side of fetal viability, if an accurate gestational age is not immediately known at the time of the patient's presentation, physical examination may be used as a surrogate indicator for an estimated GA of at least 20–24 weeks (Fig. 19.1). Initial evaluation of a reproductive-age woman should include a concise and focused obstetric and gynecologic history, with universal pregnancy testing performed [22]. In some instances, early pregnancy may be diagnosed during surgeon-performed ultrasound [25].

A Kleihauer-Betke (KB) test should be performed in all pregnant trauma patients, regardless of Rh status, to identify significant feto-maternal haemorrhage and guide anti-D immune globulin treatment in Rh(D)-negative women [26, 27]. All pregnant Rh(D)-negative trauma patients should receive anti-D immune globulin therapy due to the risk of feto-maternal hemorrhage and subsequent alloimmunization. A standard dose of 300 μg is given, with additional doses pending results of the KB test, where the extent of feto-maternal hemorrhage is quantified. The blood bank should be consulted for dose calculation, timing, and route of administration. There is no relationship between the severity of maternal injury and the incidence of feto-maternal hemorrhage [17, 26], but a positive KB test has been associated with subsequent preterm labor after maternal trauma with the extent of feto-maternal hemorrhage correlating with the likelihood of preterm labor [26]. Fetal complications of feto-maternal hemorrhage include neonatal anemia, cardiac arrhythmias, and fetal death [13]. In cases of significant feto-maternal hemorrhage, fetal intrauterine transfusion may be required.

Preeclampsia is defined as hypertension with proteinuria or adverse conditions (Table 19.2) [28]. Complications of preeclampsia may result in traumatic injuries, such as a motor vehicle collision secondary to visual impairment. Differentiating symptoms of preeclampsia from those of traumatic injury may therefore be difficult in such situations. An eclamptic seizure may mimic traumatic brain injury. Abdominal pain and placental abruption may result from preeclampsia or sustained blunt trauma. Coagulopathy may be caused by preeclampsia-induced disseminated intravascular coagulation or a consumptive process secondary to ongoing traumatic hemorrhage. In each scenario the correct diagnosis is required to tailor and guide treatment.

A search should be made for conditions unique to the injured pregnant patient, such as blunt or penetrating uterine trauma, placental abruption, preterm labor, or premature rupture of membranes. Preterm labor complicates up to 5 % of maternal traumas [17] and may be treated with tocolytics. Corticosteroids such as betamethasone or dexamethasone should be administered to patients between 23- and 34-week gestation in the setting of preterm labor or premature rupture of membranes in order to promote fetal lung maturity [29, 30]. However, delivery should not be delayed to achieve corticosteroid benefit if obstetrically indicated (e.g., significant placental abruption, fetal distress).

A qualified surgeon and obstetrician should be consulted early in the evaluation of a pregnant trauma patient. In the setting of blunt trauma, splenic and retroperitoneal injuries are more common in pregnancy because of increased vascularity [13, 31], and pelvic fractures have been reported to cause direct fetal skull fractures or intracranial injuries [32–34]. In the setting of penetrating trauma, a trauma surgeon should be involved for consideration of surgical exploration to rule out bowel or diaphragmatic laceration [12, 35]. The pattern of anticipated injuries is modified by pregnancy, with upper abdominal penetrating injuries more likely to result in bowel injury due to cephalad displacement from the gravid uterus, versus decreased visceral and retroperitoneal injury with lower abdominal penetrating injuries (but higher uterine and fetal injuries in such cases), where more non-operative management may be considered [35]. Diagnostic peritoneal lavage, if performed, should employ the open technique, above the uterine fundus [36]. Exploratory laparotomy is typically well tolerated and preferable to delayed diagnosis of intra-abdominal injuries, but is associated with an increased risk of preterm labor [37]. Excessive uterine manipulation and maternal hypotension must be avoided. Careful consideration should be given to the need for cesarean section, with the determination of fetal age, fetal maturity, and fetal well-being factored in the decision making. Cesarean section will increase the intraoperative blood loss and operative time, while delayed recognition of fetal distress will increase the risk of perinatal loss [38]. Hysterotomy in the setting of an otherwise uninjured uterus may be necessary for adequate abdominal exploration or repair of identified injuries [16, 39]. If not required at the time of laparotomy, hysterotomy may be avoided in cases of fetal demise where induction of labor may be preferred [39].

Formal uterine and pelvic examination should be performed by the obstetrical team, if available, to evaluate for uterine contractions or tenderness, vaginal bleeding, rupture of membranes, or cervical dilation in addition to evaluation for vaginal lacerations in the setting of pelvic fracture.

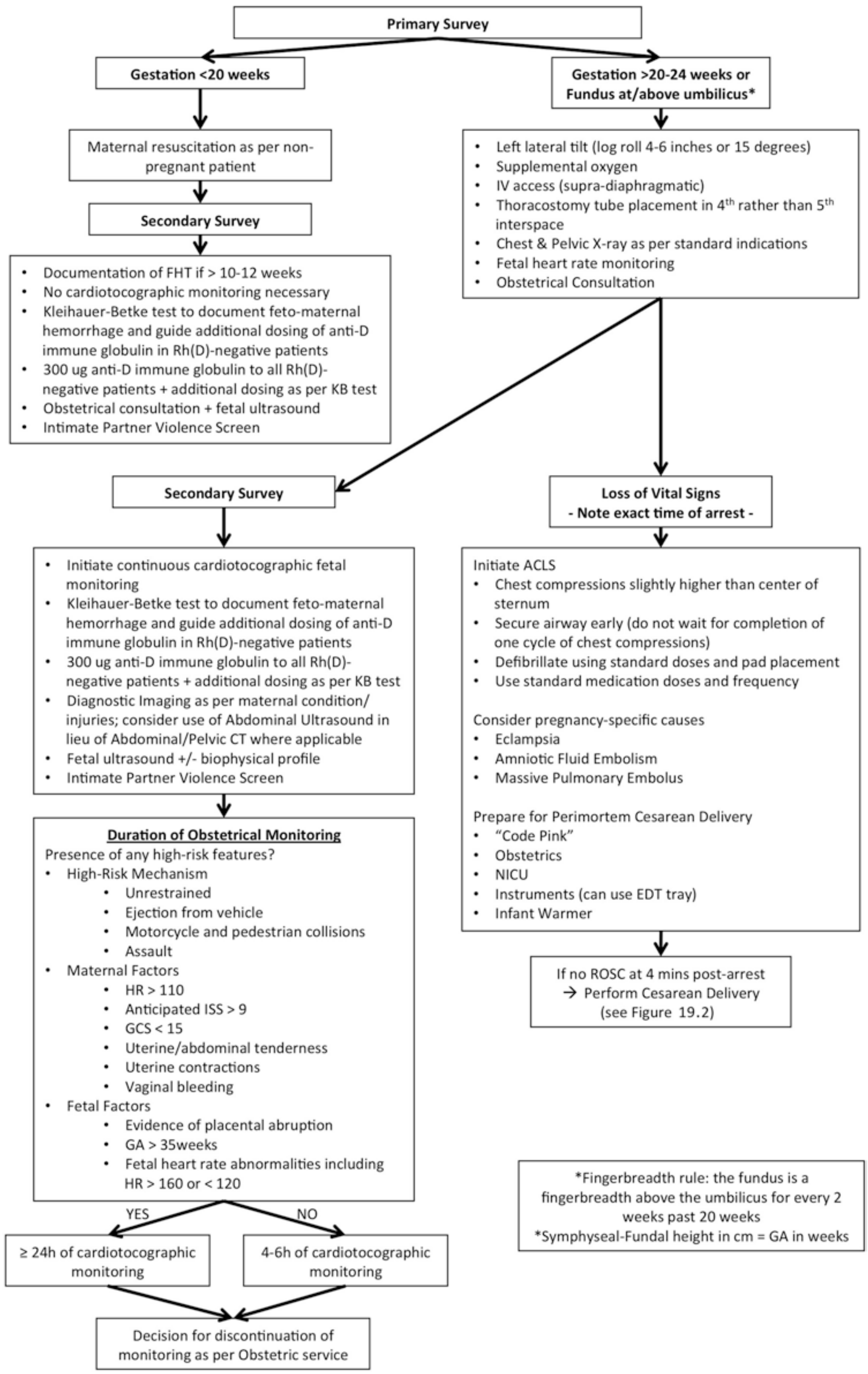

Fig. 19.1 Assessment and management of the pregnant trauma patient. Based on the content in Katz, 2012 [65]. *ACLS* advanced cardiac life support, *CT* computed tomography, *EDT* emergency department thoracotomy, *FHT* fetal heart tones, *GA* gestational age, *GCS* Glasgow coma score, *HR* heart rate, *ISS* injury severity score, *NICU* neonatal intensive care unit, *ROSC* return of spontaneous circulation

Table 19.2 Adverse conditions associated with preeclampsia [28]

Symptoms and signs
Maternal symptoms
Persistent or new/unusual headache
Visual disturbances
Persistent abdominal or right upper quadrant pain
Severe nausea or vomiting
Chest pain or dyspnea
Maternal signs
Eclampsia (seizure)
Severe hypertension (systolic BP ≥ 160 mmHg)
Pulmonary edema
Placental abruption
Abnormal maternal laboratory testing:
Elevated serum creatinine, AST, ALT, or LDH
Platelet count <100 × 10^9/L
Serum albumin <20 g/L
Fetal morbidity
Oligohydramnios
Intrauterine growth restriction
Absent or reversed end-diastolic flow in the umbilical artery by Doppler velocimetry
Intrauterine fetal death

ALT alanine transaminase, *AST* aspartate transaminase, *LDH* lactate dehydrogenase, *BP* blood pressure

Table 19.3 Intimate partner violence screen [22]

1. Have you been kicked, hit, punched, or otherwise hurt by someone within the past year? If so, by whom?
2. Do you feel safe in your current relationship?
3. Is there a partner from a previous relationship who is making you feel unsafe now?

Amniotic fluid can be identified by its alkaline pH and characteristic ferning pattern on microscopy. Cardiotocographic monitoring must be skillfully interpreted for fetal heart rate abnormalities. Venous thromboembolism prophylaxis should be provided in the form of low-molecular-weight heparin as per standard therapy. Obstetrical follow-up should be arranged to ensure identification and management of late complications, since adverse obstetrical outcomes such as preterm delivery and low birth weight are increased in trauma patients [5, 40]. Screening for intimate partner violence is essential (Table 19.3).

Fetal Monitoring

Continuous cardiotocographic fetal monitoring should be performed in all viable pregnancies (i.e., beyond 20–24-week gestation), since maternal hemodynamic parameters are not accurate predictors of fetal distress or risk of fetal loss [38, 41]. Cardiotocography will identify signs of placental abruption, fetal distress, and uterine contractions if monitored by a team member with experience in fetal heart rate interpretation. Care must be taken to distinguish the maternal versus fetal heart rate during monitoring. Continuous tachycardia, bradycardia, or repetitive decelerations may be indications for urgent delivery. Monitoring should continue throughout maternal resuscitation and continue for a minimum of 4–6 h in the absence of risk factors for fetal loss in an awake, asymptomatic patient [13, 42], versus ≥24 h in the presence of risk factors or altered level of consciousness (Fig. 19.1) [43] since the risk of immediate complications are increased in these patients [5]. Uterine rupture is strongly correlated with fetal mortality, the signs of which may be missed during assessment of the mother alone [44]. Monitoring should be performed regardless of the apparent low severity and location of injuries sustained by the mother, as fetal compromise has been identified in up to 20 % of cases of apparent minor injury [41, 43]. Placental abruption has been reported in 3 % of cases of minor abdominal injuries and 40 % of cases of severe blunt abdominal trauma where fetal mortality may be as high as 60 % [44, 45]. Similarly, the symptoms of placental abruption may be minimal, depending on the location of retro-placental bleeding and the degree of placental detachment. Even ultrasound may fail to identify placental abruption in 50 % of cases [46, 47]. Such adverse outcomes, however, are expected to manifest within 4–6 h of presentation [43]. In the presence of a reassuring fetal heart rate pattern for 4–6 h, in the absence of uterine contractions (<6 contractions per hour) at a gestational age of >20 weeks, the incidence of late fetal or maternal complications has been found to be minimal and safe discharge following maternal clearance is supported in appropriately selected patients [44].

Radiology

The risk of fetal radiation exposure must be balanced with the benefit of radiographic investigations and/or image-guided procedures. It is impossible to reap the benefits of minimized radiation exposure unless one is alive to do so. It should be emphasized that the best initial treatment for the fetus is the provision of optimal resuscitation of the mother.

Imaging and investigations—including the use of iodinated contrast material—necessary to facilitate diagnosis and management of the injured pregnant patient are endorsed in guidelines published by the American College of Obstetricians and Gynecologists [48] and the American College of Radiology [49]. Consideration should be given to the degree of fetal radiation exposure in the selection of imaging modalities where a choice exists, and abdominal-pelvic lead shielding used where appropriate. Radiation levels should be kept as low as reasonably achievable and the

Table 19.4 Fetal absorbed dose from selected radiographic examinations

	Fetal absorbed dose		
Procedure	ACOG No. 299 [48]	McCollough et al. [84]	Wieseler et al. [50]
Plain radiographs			
Chest (AP and lateral)	0.02–0.07 mrad	0.2 mrad	–
Abdominal (single view)	100 mrad	100–300 mrad	–
Extremities	–	<0.1 mrad	–
Cervical spine (AP and lateral)	–	<0.1 mrad	–
Thoracic spine (AP and lateral)	–	0.3 mrad	–
Lumbar spine (AP and lateral)	–	100 mrad	–
CT scans (*single acquisition*)			64-row multidetector
Head	<1,000 mrad	0	–
Chest (routine and for PE)	<1,000 mrad	20 mrad	2 mrad
Abdomen and lumbar spine	3,500 mrad	–	–
Abdomen	–	400 mrad	130 mrad
Abdomen and pelvis	–	2,500 mrad	1,300 mrad
Abdomen for stones (kidneys, ureters, and bladder)	–	1,000 mrad	1,100 mrad
Angiography	–	–	1,300 mrad
Angiography of aorta (chest through pelvis)	–	3,400 mrad	–
CT pelvimetry	250 mrad	–	–
Background fetal dose for 9 months of pregnancy	–	50–100 mrad	–

Notes: A radiation shield is typically applied over the gravid abdomen when not in the imaging field although the effect is minimal
1 rad = 1,000 mrad = 0.01 Gray (Gy)
<5 rad is generally accepted as a safe total fetal absorbed dose during pregnancy [48]
AP Anteroposterior, *CT* computed tomography, *PE* pulmonary embolism

use of specific dose-reduction techniques should be applied [50]. A medical physicist should be involved to calculate the actual fetal dose received, with prospective fetal dose estimation through placement of dosimeters on the patient at the level of the uterus a useful adjunct [50].

Fetal risks of anomalies, growth restriction, or spontaneous abortions are not increased with radiation exposure of <5 rad (1 rad = 10 mGy (milligray)) [48]. Table 19.4 lists estimated *fetal* exposure levels from common radiologic procedures. When tabulated using this data, a diagnostic imaging work-up that includes chest and pelvic plain radiographs, extremity radiographs, and a "pan-scan" (CT of the head, cervical spine, single-phase CT chest/abdomen/pelvis including thoracolumbar spine) would not necessarily exceed the threshold of 5 rad. Indeed, Tien et al. [51] examined actual delivered radiation doses in trauma patients admitted to a Canadian Level 1 trauma center and found a mean dose of 2.27 rad with an average of 4.9 CT scans and 13.7 plain radiographs performed during their hospital stay. However, some modalities may expose the fetus to doses of radiation that exceed the safe limit, such as pelvic angiography and embolization in the setting of pelvic fracture. Such patients should be counseled appropriately by the obstetrical or perinatology service. The teratogenicity of radiation in pregnancy is most pronounced in the first trimester, highlighting the need for universal pregnancy testing in women of reproductive age [22, 52]. In addition, while no in vivo tests in animals have demonstrated mutagenic or teratogenic effects with low-osmolality contrast agents there are no good studies in pregnant women, and there are theoretical concerns of hypothyroidism developing in the newborn infants [53]. Therefore, the American College of Radiology suggests that these agents should ideally be used in pregnancy only if (a) the information cannot be obtained without contrast administration, (b) the information will affect the care of the patient during pregnancy, and (c) the exam is urgent and cannot be delayed until after pregnancy [53]. Obviously most trauma imaging would satisfy these criteria.

Valuable information about the state of the fetus can be obtained from both plain radiographs as well as CT imaging. Plain radiograph findings such as the presence of extended fetal extremities, abnormal fetal position, or free intraperitoneal air can suggest a diagnosis of uterine rupture [22]. CT scan may identify placental abruption with both a sensitivity and negative predictive value of 100 % when images are appropriately interpreted [54–56] with the degree of placental enhancement associated with the subsequent need for delivery [56]. Correlation of imaging and cardiotocographic findings may improve the specificity and positive predictive value of such scans and appropriately triage patients for further evaluation versus safe discharge.

Abdominal ultrasound, in general, is less sensitive for the detection of injuries in the pregnant patient compared to the nonpregnant patient; however, its specificity is preserved [57]. FAST is used frequently in trauma patients to detect free fluid, presumed to be hemoperitoneum and a sign of intra-abdominal injury. The finding of free fluid may be difficult to interpret in women of reproductive age, since free fluid may be associated with the menstrual cycle [58]. However, Hussain et al. demonstrated the presence of pelvic fluid in <7 % of non-traumatically injured pregnant patients with a volume never exceeding a depth of 4 mm [59], thereby supporting the utility of FAST in this population.

Perimortem Cesarean Delivery in Trauma

Emergency hysterotomy, or perimortem cesarean delivery (PCD), is the expeditious surgical delivery of a fetus while the mother is in a state of cardiac arrest. Historically, this was used as a procedure of last resort to attempt "fetal salvage" after failure of maternal resuscitation. In the 1980s, reports of maternal recovery after fetal delivery were published. Analysis by Katz and colleagues led to the "Four-Minute-Rule," whereby "cesarean delivery should be begun within 4 min and the infant delivered within 5 min after maternal cardiac arrest" [60], the validity of which was reaffirmed in a follow-up study 20 years later [61]. Seventy percent of surviving infants were delivered within this time interval, while neonates delivered outside of the 5-min window were more likely to demonstrate neurological compromise [60]. Physiologically, evacuation of the gravid uterus has a number of beneficial maternal effects: it (1) alleviates IVC and aortic compression and thereby improves venous return; (2) allows for more mechanically effective CPR; and (3) allows redistribution of the low-resistance uterine blood flow to other organs [45, 61, 62]. The benefits of PCD therefore extend beyond the fetus and may positively impact the ability to successfully resuscitate the mother [61]. Following cesarean section, cardiac output may increase by 30 % and tissue perfusion requirements may significantly decrease, both thought to be advantageous in the setting of maternal resuscitation [63, 64]. See Fig. 19.2 for details on performing a PCD.

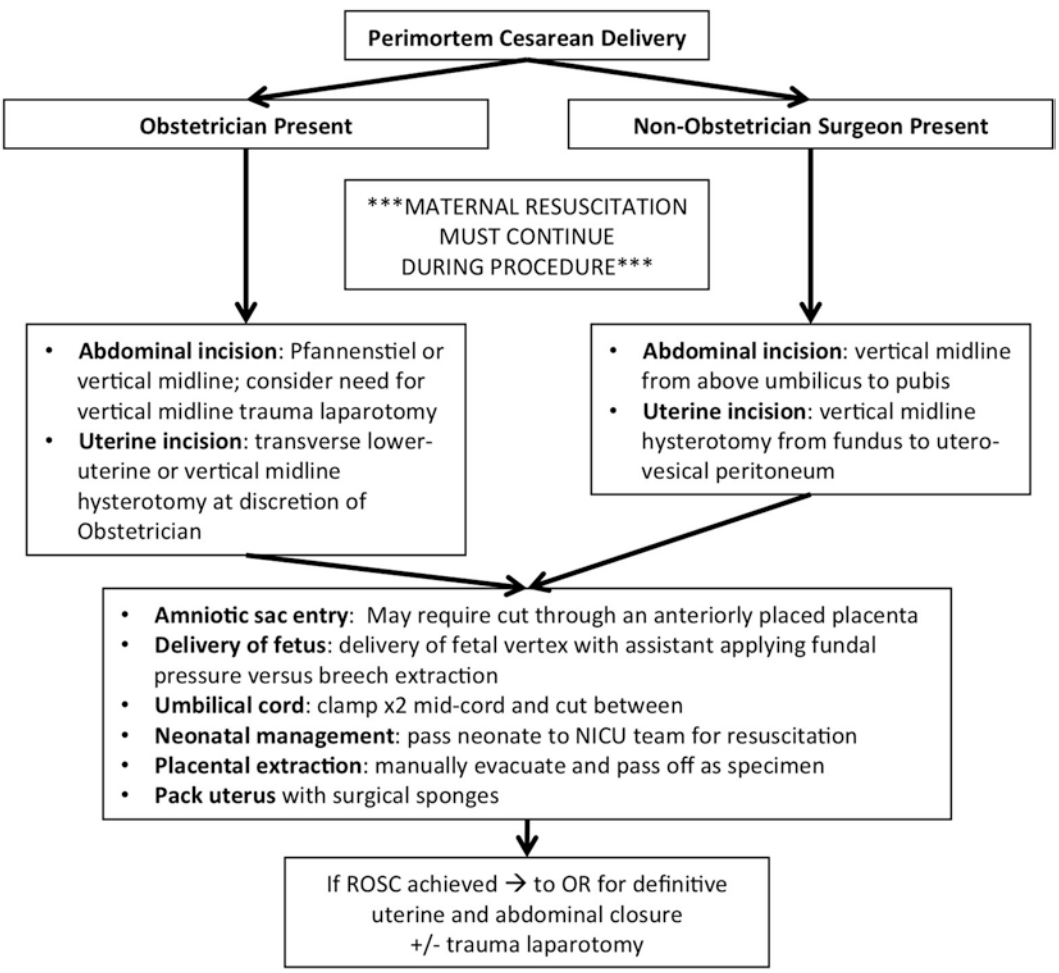

Fig. 19.2 Perimortem cesarean delivery. *NICU* neonatal intensive care unit, *OR* operating room, *ROSC* return of spontaneous circulation

Specifically addressing the pregnant trauma patient, Morris et al. reviewed almost 115,000 trauma admissions from 1986 to 1994 at nine Level-1 US trauma centers [38]. They identified 441 pregnant women with 32 emergency cesarean deliveries, with an overall maternal and fetal survival rate of 72 % and 45 %, respectively. Only three of these were true PCDs in the setting of maternal cardiac arrest. The authors found that a lack of pre-cesarean fetal heart tones predicted a 100 % fetal mortality. The reliable exclusion of fetal heart tones in a busy trauma bay with a rapidly evolving clinical situation presents challenges. While the use of surgeon-performed trauma ultrasound to examine for fetal cardiac activity has been reported and suggested to supplant fetal heart tones in the setting of maternal collapse [65] the necessity of spending valuable time to confirm viability is questioned, given the potential for improved maternal resuscitation. Therefore, PCD is advocated irrespective of whether viability of the fetus can be confirmed [66].

Currently, guidelines from the American Heart Association [67], the European Resuscitation Council [68], and the Eastern Association for the Surgery of Trauma [69] include PCD as part of the treatment of a pregnant patient who has sustained a cardiac arrest. The successful use of PCD in pregnant trauma patients continues to be reported [70, 71].

Coordination of Specialties in the Trauma Bay

As discussed in Chap. 8, the trauma bay is often a complex and challenging environment and requires an effective team to optimally resuscitate a severely injured patient. The presence of a trauma patient who is also pregnant has the potential to amplify the stress of the situation and generate powerful emotional responses from the team members. Despite this, trauma evaluation and resuscitation must proceed in a systematic fashion, with care coordinated by the TTL between the trauma team and the obstetrical service.

Despite apparent minor injuries, pregnant patients may develop fetal complications. As such, all pregnant patients should be assessed by the obstetric service with appropriate monitoring and follow-up [69, 72]. Meanwhile, studies have shown that pregnancy itself as a sole criterion for trauma team activation (TTA) is not useful; standard physiologic, mechanistic, and anatomic activation criteria are sufficient to identify those patients requiring the response of the trauma team [72, 73]. A practical approach is that of TTA *only* when the patient meets standard institutional TTA criteria with the inclusion of the obstetric service in the TTA if the patient is known or suspected to have a gestational age of >20 weeks.

In response to the challenge of providing emergency obstetrical care, a number of programs and courses have been created including ALARM [74], MOET [75], ALSO [76], and MORE$^{OB®}$ [77]. The importance of inter-professional team function and use of crisis resource management skills are increasingly being recognized and incorporated into many of these programs. Indeed, the introduction of the MOET course into the Netherlands has been associated with an increased rate of perimortem cesarean delivery in the setting of maternal cardiac arrest (a recommended procedure in this setting) [78]. The use of simulation is advocated to help improve the performance of obstetrical teams in such situations [66] and has been demonstrated to be effective [79–81]. The implementation of standardized institutional responses to obstetrical crisis (e.g., "Code Pink") [82] with obstetric emergency teams contributes to effective management of such crises on a hospital-wide basis [83].

Optimal management of the severely injured pregnant trauma patient is predicated on the successful incorporation and integration of obstetrical services into the trauma team. Strategies to achieve this include the use of clear activation criteria, institutional obstetric emergency teams that can respond to the trauma venue, and multidisciplinary simulation-based team training.

Conclusions

Care of the traumatically injured female patient increases in complexity when she is also pregnant. While the majority of such traumas do not result in severe injuries to the mother, they can result in significant and sometimes occult or delayed consequences to the fetus. Successful resuscitation and management of the pregnant trauma patient require knowledge of and attention to pregnancy-specific physiologic changes and spectrum of potential injuries, and appropriate integration of obstetrical services into the trauma team with preparation for extreme cases that may require rapid obstetrical intervention. The management of any severely injured trauma patient requires careful coordination of a multidisciplinary team. There is no situation that more aptly demonstrates the necessity for a team approach than the management of trauma in pregnancy.

Key Points

- Physiologic adaptations to pregnancy result in a hyperdynamic and hypervolemic state which may be misleading in the trauma setting where blood pressure and heart rate do not reflect the degree of maternal shock.
- Normalcy of vital signs in the mother does not accurately reflect the status of the fetus, necessitating cardiotocographic monitoring for the early

(continued)

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identification of obstetrical complications and fetal compromise.

- Fetal outcome is directly related to maternal outcome; maternal resuscitation and treatment are paramount.
- The presence of a fetus adds an additional layer of complexity in the care of injured pregnant patients, not only due to potential obstetrical complications but also due to the emotive aspect this may have on the trauma team.
- A multidisciplinary approach that includes obstetrics should be employed in the management of pregnant trauma patients.

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Medical Comorbidities and Trauma

20

Harvey G. Hawes and John B. Holcomb

Introduction

The sum of injury deaths worldwide in 2010 was greater than malaria, tuberculosis, and HIV combined, and has increased by at least 24 % over the last decade [1]. This staggering trauma pandemic has been thought to predominately impact the young healthy portion of the population. However, when intentional and unintentional injury data are combined, the greatest years of life lost in the USA is due to trauma *up to the age of 75*, ahead of even cardiovascular and malignant diseases [2]. Deaths from injury only represent a small fraction of the total burden of injury; roughly tenfold more people survive their injury, and many of them attempt to seek medical attention. Increasingly, the demographics of injured patients are changing. The world is aging and as they age they collect a list of medical comorbidities. It is this rapidly growing segment of the population that this chapter is written about.

The term "elderly boom" describes the demographic shifts in the western world and the effects of aging baby boomers on healthcare demands [3]. This segment is growing at around twice the rate of the general population and is projected to make up 20 % of the total US population by 2050 [4]. While life expectancy has risen steadily to an all-time high (81.1 years combined; 78.8 for women, 83.3 for men in Canada) [5], it should be appreciated that this peak is concurrent with compounding medical comorbidities. It is predicted that in the next 5–10 years, injured patients over the age of 60 will make up 50 % of the total visits to trauma centres [6].

The number of identified medical comorbidities increases with age [7]. Roughly 10 % of patients under the age of 19 exhibit multimorbidity, that is, more than one identified medical comorbidity. This number jumps to almost 80 % at age 80 in primary care patients [8]. Whether this number reflects the incidence of preexisting medical conditions in trauma patients is only starting to be appreciated. A recent study from Quebec looking at injured patients over the age of 65 admitted to a level I trauma center identified 57 % of patients with hypertension, 34 % with cardiac disease, 22 % with diabetes, and 22 % with dementia [9].

The old assumptions of a healthier, fitter older generation are set to change over the coming decades. Obesity rates in males over 75 years of age in the USA have doubled from 1988 to 2008. According to 2010 US census data, less than 12 % of people over 65 meet federally recommended activity guidelines [4]. What is now becoming clearer is the impact of other comorbidities on activity levels, with diabetes, Parkinson's, and obesity being associated with increased levels of *in*activity [7]. Injury patterns change with activity levels. Potentially high-energy injury mechanisms decrease as people drive less, or leave their residence less. As such, injuries from falls, such as closed head injury or hip fractures, predominate in this cohort.

Several preexisting medical comorbidity metrics have been developed in an attempt to quantify the significance of various diagnoses. The Charlson Index [10], and its derivatives, is a weighted scoring system to predict mortality over 10 years based on either a nurse-administered questionnaire or a patient self-reported form. Medical comorbidities can affect all aspects of the injury process, not just a given patient's response after injury has occurred. We define a medical comorbidity as described by Elixhauser [11], as "… a clinical condition that exists before a patient's admission to the hospital, … and is likely to be a significant factor influencing mortality and resource use." For the purposes of trauma it makes sense to look at the effects of medical comorbidities across all phases of injury. For the purposes of this chapter, we consider these to include the pre-injury, injury, and recovery phases.

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Pre-injury Phase

Over the past decades, injury prevention has moved to the forefront of our discussions of trauma burden. While issues like seatbelts, road safety, and helmet use have been extensively studied, risk reduction through optimizing care of chronic medical conditions is a new idea. Either the disease process itself or the injury related to these diseases may lead to decreased quality of life and disability; this may add another dimension to the discussions between healthcare providers and patients. The best studied of these medical conditions that predispose patients to injury are drug and alcohol dependence, and age-related cognitive and mobility changes. Others, like morbid obesity, which confers an increased risk of nonfatal injury [12], are only now being investigated, especially in the workplace [13], and in the elderly [14].

Chronic Alcohol and Drug Use

Excessive drinking, as is seen in chronic alcohol abuse, is the single most important risk factor for injury. Alcohol is a factor in 32.4 % of patient visits to trauma centers [15], and one-half of all alcohol-related deaths are from injury [16]. Recent initiatives to provide brief counseling to injured patients while in hospital as a method of reducing future injury events have been found to be both effective [17] and cost effective [18], and are being implemented in trauma centers across North America.

While illicit drug use rates have fallen in Canada over the past decade, young people aged 15–24 abused these drugs five times more than all other age cohorts. Worldwide, some 200,000 deaths per year are related to illicit drug use, with injury playing a major role [19]. Illicit drugs, however, represent only a portion of the total drug use. One-third of all prescription drugs used in the USA are by the elderly, who have on average more than five prescribed medications at a given time. The age cohort 50–65 currently uses the largest proportion of psychoactive prescription drugs, a number that could exceed illicit drug use [20]. It is projected that by 2020 up to a third of this age group will require drug dependency treatment as the rate of nonmedical use of prescription drugs increases [19]. There are also increased risks of injury with the use of non-psychotropic medications. For example, initiation of antihypertensive agents has been associated with increased fall risks [21].

Suicide Risk

Suicide is the eighth largest cause of death per year in some regions of the USA [22]; it is third largest cause of years of potential life lost, behind motor vehicle collision and violence, and accounts for 1.3 % of all deaths per year globally [23]. Preexisting depression, drug or alcohol abuse, and posttraumatic stress disorder are the major risk factors for suicide attempts or deaths [24, 25]. Suicide rates range around 11 % in drug-abusing youth populations. Only 1 in 25 suicide attempts by young people are successful, and the survivors represent a much larger burden on the healthcare system. Elderly greater than 75 have the highest suicide rates, with risk factors including serious physical illness and depression [26]. Increasing access to depression and drug addiction treatment for identified at-risk individuals has consistently shown decreases in suicide attempt rates [27].

Driving Risks

Age-related changes in cognition, reaction times, mobility, and vision are all important when performing medical assessments of older drivers. Legislation varies from region to region regarding which body determines fitness to drive, and the role physicians play. What is similar is the multimodal assessment across cognitive, medical, comorbid illness, and mobility scales [28]. Older drivers may be the safest age cohort in terms of absolute numbers, but contribute the most collisions per distance traveled.

These numbers are going to only increase, and by 2020 there are projected to be 40 million elderly drivers on US roads [29]; they are projected to be involved in one-sixth of all traffic collisions. There are often trade-offs to recommending a patient not to drive, and these can make the discussion difficult for some clinicians. Guidelines for physicians have been published by the American and Canadian Medical Associations; however adherence to them has not been universal.

Further, concerns over drivers of any age with significant medical comorbidities are valid, with US data indicating some 20,000 collisions per year linked to this group [30]. Relative risks of collisions are increased most with cardiovascular and neurologic diseases, and mental disorders. Other medical conditions, unrelated to age and polypharmacy use, may increase road traffic injury rates as well, though the literature is contradictory. Take for example obstructive sleep apnea, seen in as many as 45 % of obese people [31], with sleep deprivation a causative factor in roughly 20 % of all vehicle collisions [32].

Fall Risks

Falls represent the single largest mechanism of injury in the elderly. A third of older patients in the community fall per year, and half of those fall again soon after. Ten thousand elderly patients succumb to the consequences of falling annually in the USA [33], with an observed mortality rate in patients over 70 years old of 4 % after ground-level falls [34].

Nonfatal falls result in an inordinate number of fractures, though nonfatal head injuries are common as well. The cost burden from caring for these injuries is over $19 billion in the USA [33]. This segment is particularly at risk due to extrinsic and intrinsic factors. Examples of extrinsic factors are uneven flooring, poor footwear, inadequate lighting, and play less of a role as people age. Intrinsic factors are numerous, and worsen with age. Decreases in mobility, and fall avoidance mechanisms, in addition to the effects of polypharmacy are common. Add to this osteopenia or osteoporosis, which lessens the fracture threshold, and it is easy to understand the healthcare and economic burden falls have.

Injury Phase

Over the preceding decade, the culmination of changes to pre-hospital and initial resuscitation of trauma patients has led to reductions in early hemorrhagic deaths and those in the immediate ICU management [35]. This reduction in mortality however is not as successful in older patients or in those with preexisting medical conditions [36]. While these patients tend to suffer late consequences of their disease after the injury phase (see next section), there are considerations during their early trauma care that can aid recovery.

Leading a successful resuscitation strategy for a critically injured patient requires an understanding of the physiological response to shock, mechanisms, and methods of correcting coagulopathy, and knowledge of the risks and benefits of the various resuscitative measures. Medical comorbidities and the aging process can alter each of these aspects of trauma resuscitation, and when compounded may have dire consequences.

Hemorrhagic shock, the primary causative factor for early death from severe injury, leads to increasingly well-understood physiologic consequences. Reversal of these physiologic derangements and subsequent support until a patient's homeostatic mechanisms resume are the goals of resuscitation. Once the limits of the innate physiologic response to hypovolemia are reached, shock ensues. The ability of a patient to tolerate a shock state, and the resuscitative measures themselves, may determine the amount of time a trauma team has to stop bleeding and restore homeostasis. The ability of a patient to tolerate these efforts often limits survivability of a given set of injuries.

The term "homeostenosis" describes the loss of physiologic reserve due to aging. While this is difficult to study in isolation apart from concomitant comorbid disease, there is consensus in the geriatric literature regarding the concept [37]. The idea of a physiologic precipice, one that once crossed leads to a disastrous outcome (death, cardiac arrest, etc.), has been put forward. As more of the available physiologic reserve is used just to maintain health while aging, less is available to overcome massive perturbations such as is seen in injury. One area requiring study is the impact of multimorbidity on homeostenosis in younger patients; perhaps the concept of frailty (discussed later) will address this issue.

Alterations in cardiopulmonary physiology due to medical comorbidities such as chronic chronic congestive heart failure (CHF), ischemic heart disease, or chronic lung disease greatly limit a patient's shock tolerance. A study looking at the relationship of cardiac disease and trauma outcomes [38] found increases in mortality rates with CHF, pre-injury beta-blocker use, and warfarin use. For example, pre-injury CHF, when combined with significant chest injury, can lead to a fivefold increase in mortality rates over patients without CHF.

When looking at the isolated effects of single-drug agents on aspects of injury, there are a few points worth noting. Pre-injury beta-blocker use itself may not lead to increased mortality, though slower presenting heart rates and bradycardia may be seen during resuscitation [39]. With anticoagulants, the effects are clear, especially with closed head injuries [40]. Warfarin use prior to head injury does increase progression of disability and mortality. A protocol of early risk recognition, and reversal with vitamin K and plasma products, has been shown to mitigate this risk [41]. Using four factor (Factors II, VII, IX, and X) prothrombin concentrate has shown some initial promise [42] while potentially avoiding the difficulties of using large doses of plasma, including large-volume administration in a patient with tenuous cardiac physiology, blood-borne infections, and transfusion-associated lung injury (TRALI) [43]. Questions regarding thrombotic risk, duration of efficacy, and overall cost–benefit analysis between prothrombin concentrates and plasma products have yet to be conducted. Quite different from warfarin, anticoagulation reversal is more difficult with antiplatelet agents, especially aspirin and clopidogrel [44], and much more worrisome are the direct thrombin inhibitors, to which no expeditiously efficient reversal means exist [45, 46].

Given the changes in physiologic response due to aging, some have suggested changes in triage criteria [47] and increased use of intensive invasive [48] and noninvasive [49] monitoring in the elderly trauma population. As such, recent guidelines by various trauma associations recommend age criteria for trauma team activation, noting prior significant under triage, and increased mortality in patients >70 years of age.

Surgical Management Strategies of Severe Injury

In addition to changes in physiologic reserve associated with multimorbidity, aging, or use of medications, the specific management of certain injuries can differ also. Though now widely accepted in younger patients, non-operative management of significant liver and spleen injuries as the result of blunt trauma is more likely to fail in patients older than

55 years [50]. As well, mortality from these injuries is higher in elderly patients. There has been an evolution in the recommendations from various trauma associations regarding the exclusion criteria for non-operative management of blunt solid organ injury. Low thresholds for conversion to operative management for even brief episodes of hypotension [51], in the setting of intensive care monitoring, were shown to reduce the risk of mortality in these fragile elderly patients to the same levels as younger patients. The role of angioembolization as an alternative to surgery has not been well studied in these patients.

As discussed in Chaps. 14 and 15, damage control surgery (DCS) is now common practice and may be considered as a modality of trauma resuscitation. A recent trauma database review looking at DCS in patients over and under 55 years of age [52] indicates that although mortality rates are higher in the older cohort, significant numbers of these patients survive to discharge. Age alone is not a contraindication to performing DCS, and it should be included in the list of possible life-saving efforts.

Recovery Phase

Recovery from injury and return to the general population are probably most affected by comorbid disease and age. At best, the patient is left with their preexisting illness and infirmity. Commonly, though, recovery and rehabilitation periods in these patients are protracted, limited, and fraught with complications.

Outcomes After Injury

Perhaps the best studied aspect of trauma care with patients with medical comorbidities is outcomes. As more effective trauma systems were developed over the later half of the last century, the causative factors of mortality changed. Early deaths from hemorrhagic shock have decreased dramatically as rapid pre-hospital transport developed, and early resuscitation strategies evolved. These great strides made in trauma care are in part due to the development of specialized trauma centers. Alarmingly though, these improvements are not seen in older adults when treated at the same specialized centers [53]. The nature of death after major trauma is now shifting; we are now seeing deaths occur later in the hospital stay in patients with preexisting medical comorbid disease.

Mortality increases with age and preexisting medical conditions across all levels of injury, but particularly in the intermediate injury severity range [54]. A clear doubling of the ISS-matched mortality rate for the elderly compared to younger adults has been shown [55]. Older patients seem to have a bimodal time distribution for death when compared to younger patients. Severely injured older patients tend to die earlier, during resuscitation, or if they survive this phase, later from complications of their comorbidities [56]. A small component of these early deaths may include a bias towards earlier withdrawal of care decisions, perhaps from those with advanced directives. The late deaths can be from causes completely unrelated to their presenting injuries.

Initial case–control studies have provided estimates of the contributions of various preexisting medical conditions on mortality after trauma [57]. Cirrhosis, congenital coagulopathy, coronary artery disease, chronic lung disease, and diabetes all seem to be implicated, with relative odds ranging from 1.2 to 4.5 in multiple regression models. However, the compound effects of these conditions are more difficult to tease out of retrospective studies. For example, outcomes for obese patients may be worse [58] or better (the protective "obesity effect") depending on how studies control for chronic illnesses like diabetes and heart disease [31]. The same can be said for other studied comorbid diseases such as hypertension, heart disease, and diabetes. The effects of multimorbidity may impact mortality more in the "young old" (aged 50–65) for reasons that are unclear as of yet [9].

Fractures and Mortality

Perhaps best known is the increased risk of mortality with multimorbidity and age after hip fracture [59, 60]. What is interesting is how evenly distributed chance of dying is over the following 6 months, indicating the need for continuous vigilant care of preexisting medical conditions and providing aggressive physiotherapy services. Clearly, with respect to hip fractures, the real work of improving outcomes starts after operative management has been completed.

Delayed Complications and Mortality

For multisystem-injured patients, after surviving the initial resuscitative phase, there are also marked differences in the recovery courses between the elderly and younger adults, and patients with multimorbidity. This difference may be seen in patients as young as 45 years of age, after which significant differences can be seen in length of stay, end-organ and infectious complications [61], and disposition [9]. This echoes reports of increased morbidity following rib fractures above the age of 45 as well [62]. Moreover, delayed mortality from complications unrelated to injuries sustained has been demonstrated in patients over 65 years with preexisting medical conditions, with a peak past 13 days since admission [9].

Some of these delayed risks present opportunities for interventions. Rib fracture protocols including multimodal analgesia, aggressive chest physiotherapy, lung volume expansion, and early mobilization have been successfully used to reduce the risk of pneumonia and death after multiple rib fractures in patients over 45 years of age [63]. Some have recently questioned the need for a "geriatric trauma team" in an attempt to provide comprehensive, multidisciplinary care to these challenging patients. Initial "orthogeriatrics" models have been implemented, and shown to decrease late complications in elderly patients with hip fractures [64], and a trauma surgeon-led geriatric team approach has shown similar results for multiply injured elderly patients [65], and likely represents the multidisciplinary approach necessary to address these complicated patients.

Futile Care

As our understanding of large increases in mortality in this complex segment of the population has grown, questions regarding the burden placed on healthcare systems given the poor outcomes have been looked at. Ultimately, recovery from injury can be measured by what level of function can be regained, and the level of support needed for these patients in the community. There is some indication that elderly patients (older than 75) who survive hospitalization for severe injury may have survival rates similar to those with aggressive malignancy—around 20 % 5-year survival [66]. The presence of significant head injury seemed to be the most important factor, accounting for many early deaths (within 5 days), and even for those who survive to discharge from hospital. This is not to say that all elderly trauma victims are doomed; in a study of severely injured patients older than 65 years of age, some 60 % were discharged from hospital, with over 30 % returning home [9]. What is not clear yet is the functional status or quality of life present for these discharged survivors.

Multiple attempts at generating predictive guidelines to help trauma clinicians have been developed by studying resource utilization, and healthcare cost analyses. Recent estimates of the cost-effectiveness of trauma care show a marked difference above and below the age of 55 [67]. When looking at age alone, modest head injury and shock on admission are portent of poor outcomes, with survival rates under 5 % in patients over 75 [56]. In younger patients (aged 65–74), more severe head injuries when combined with severe abdominal and thoracic injuries show similar outcomes—at an estimated cost of $750,000 per year of life saved. While age itself is not an indication for limiting care, what is largely unknown is how to prognosticate when combining age, injury severity, and comorbid disease. Early discussions regard end-of-life issues as prudent, even after successful aggressive initial resuscitation and operative care [68]. It is important to keep in mind that as we become more proficient in bringing these patients through their hospital stay with a favorable discharge, the costs above are likely to be very different.

Frailty

Given the far-reaching and interconnected effects of aging and comorbidity on trauma patients, there might be a novel way of conceptualizing these effects. Frailty is a concept taken from geriatric medicine that is being applied to the surgical arena [69]. In essence, frailty is a measure of additive defects in physiology that predispose patients to increased rates of mortality. Although affiliated with the elderly population, people of any age can be at risk of frailty.

The accumulation of physiologic defects seen as adult patients age leads to an impairment of responses to physiologic stressors. A critical precipice may be encountered, whereby further insult leads to catastrophic collapse and death. The concept of homeostenosis (see above) describes the narrowing of the amount of physiologic perturbation tolerated as these patients age, and is likely related to frailty. Thus medical comorbidities are a risk factor for frailty, and disability is an outcome.

Several frailty scores can be used, and range from surrogate inflammatory markers to single measurements such as grip strength or iliopsoas muscle bulk to the more comprehensive nurse-administered or patient self-reported scales [70]. Using these scales we know that frailty increases with age, and also with multimorbidity, independently of the normal homeostenosis of aging. Once the frail phenotypic features [69] of weakness, decreased muscle bulk, immobility, and cognitive changes are manifest in a patient, regardless of the antecedent causes, the risk of adverse outcomes is present.

In surgical patients, increased frailty leads to increased perioperative complications, institutionalization, and mortality [71]. Critically ill, frail patients also show increased adverse outcomes [70]. Encouragingly, the concept of frailty was able to successfully predict unfavorable outcomes in geriatric trauma patients in a 1-year prospective study [72].

Conclusions

The effects of preexisting medical comorbid diseases on outcomes in injured patients are becoming understood. What is clear is that there are ever-increasing numbers of injured older patients, and those with significant medical conditions. Current strategies for managing these patients consist of early identification, increased levels of monitoring, early and aggressive support of physiologic derangements, and appropriate discussions of goals of care. Recent retrospective reviews of national trauma registry data are starting to generate testable hypothesis in this new area of trauma care. Prospective trials looking to mitigate complications arising from preexisting medical conditions are due in this rapidly growing segment of our population.

Key Points

- The demographics of injured patients are changing rapidly.
- We are facing a trauma pandemic, and the injured are older and less healthy than before.
- Age and preexisting medical comorbidities impact survival during all phases of injury care.
- Aggressive triage, monitoring, and appropriate early discussions on goals of care are necessary when managing these patients.
- Despite the complexities, favorable outcomes are common, and may be predicted by concepts such as frailty.

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Part V

Emergency Ultrasound and Trauma Imaging

Basic Trauma Ultrasound

21

Markus Ziesmann, Andrew W. Kirkpatrick, Nova L. Panebianco, and Lawrence M. Gillman

Introduction

The early assessment of a potentially unstable trauma patient must be both rapid and unequivocal to best direct the diagnostic and therapeutic measures in each relevant case. Plain radiography of the chest and pelvis and Focused Assessment with Sonography for Trauma (FAST), for example, produce virtually instantaneous results that directly influence further management. The adoption of FAST as part of the trauma patient's initial physical examination has established a new standard of care and has rendered Diagnostic Peritoneal Lavage (DPL) largely obsolete (DPL is discussed further in Chap. 17). Evidence shows that POC US techniques reduce the time to surgical or other critical interventions—often before the onset of hemodynamic instability.

The FAST exam seeks to detect any abnormal fluid collection within the peritoneal and pericardial potential spaces. In the context of a hemodynamically unstable trauma victim, any free fluid signifies FAST-positivity and is assumed to represent hemorrhage. The newer, extended version of the FAST technique (E-FAST) also includes inspection of both pleural spaces to rule out pneumothorax; pleural US can also be used separately when pneumothorax is the primary concern (Chap. 22).

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The FAST Examination

Technique

A standard FAST examination is performed in a supine patient position on a level table. Most patients arrive supine with spine precautions, and will typically be disrobed during resuscitation hence ready for the FAST exam. In contrast to many other diagnostic techniques, FAST is easy to perform initially and easily repeatable.

Basic FAST consists of scanning four sites: (1) Pericardial (cardiac), (2) Perihepatic [right upper quadrant (RUQ)], (3) Perisplenic [left upper quadrant (LUQ)], (4) Pelvic (Pouch of Douglas or retrovesicular). The examination of all four sites may be performed in any order, so long as the operator successfully visualizes all four sites and approaches the exam systematically. Some sonographers have advocated starting the exam with the pericardial view which allows the operator to calibrate their device's gain setting based on the intra-cardiac blood. Others advocate starting the exam in the RUQ, as this is the region most likely to yield positive findings and in that sense may be considered the most important. Regardless of the order of examinations performed, approaching the exam in a systematic and organized way is necessary to both learn the techniques and ensure that nothing is overlooked. Examination of the thorax if proceeding to an E-FAST exam can occur before or after the abdominal examination.

The FAST exam is performed using a low frequency (2.5–5 MHz) curvilinear or phased array probe which will allow for adequate depth visualization during the study. In brief, the ultrasound device creates images based on the detection of reflected (inaudible) sound waves such that dense tissue appears bright white and non-echogenic tissue appears dark black on the ultrasound's display. The exam may be made more difficult by the presence of obesity, large amounts of gastric or small bowel gas, subcutaneous emphysema, or COPD [1], and the presence of known preexisting ascites makes the exam uninterpretable or indeterminate.

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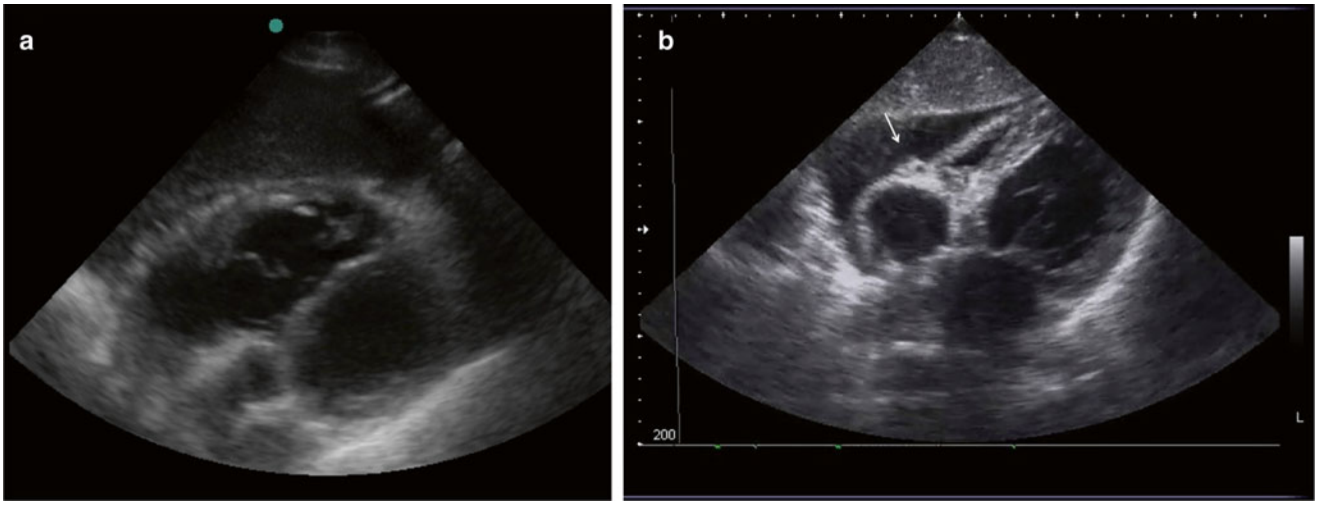

Fig. 21.1 Pericardial view of the FAST examination. Normal examination (**a**) contrasted with a positive study (**b**) with anechoic fluid visible within the pericardial space (*arrow*)

An inverse relationship exists between the depth of penetration and resolution of the scan; patients with a large body habitus may be difficult to interrogate.

Pericardial View

The pericardium is examined in the subxiphoid view using the liver as an acoustic window. The probe is placed in the subxiphoid area and angled toward the patient's left shoulder, with the pointer at 9 o'clock. Notably, the transducer is almost parallel to the skin of the torso and should be pressed firmly just inferior to the xiphoid.

The sonographer may need to sweep the transducer further to the patient's right side in order to use the liver as an acoustic window. The normal pericardium is identified as a hyperechoic (white) line surrounding the heart. Layers of connective tissue are adherent to the viscera (the heart) and to the surrounding compartment (the pericardium) with a potential space between them (Fig. 21.1a). Any anechoic fluid within this potential space (Fig. 21.1b) represents a positive study and a presumed diagnosis of hemopericardium. One common pitfall in evaluating the pericardium is to declare a positive study after mistaking an epicardial fat pad for free fluid. Epicardial fat pad is adherent to the cardiac tissue and will move with the cardiac contractions. A recently appreciated cause of a false negative pericardial FAST exam is when a large rent in the pericardium decompresses a serious cardiac injury into the pleural space rather than developing a cardiac tamponade.

When the sonographer cannot obtain satisfactory views in the subxiphoid plane, a left parasternal approach may be attempted. The probe should be placed immediately to the left of the sternum at the fourth or fifth intercostal space, initially with the probe marker to the patient's right side. After obtaining a view of the heart, the probe can be rotated with the marker towards the right shoulder and then the left shoulder, for long-axis and short-axis views, respectively. This technique may be preferred in patients with significant obesity.

Novice operators should bear in mind the following tips:

- Examine the interface between the right ventricle and the liver for pericardial fluid and thus tamponade which is the primary objective of this view.
- The presence of a small amount of fluid (non-circumferential) may be normal, while the presence of circumferential pericardial fluid along with right ventricular or atrial collapse is alarming.
- A pericardial fat pad can be hypoechoic or of mixed echogenicity (contain gray-level echoes) and most commonly is located anterior to the right ventricle.
- Obesity, prominent abdomen, abdominal tenderness, gas, as well as pneumoperitoneum/pneumothoraces may obscure the subxiphoid view thus the parasternal long/short axis views may be used as alternatives.

RUQ View

The RUQ view uses the liver as a sonographic window to evaluate for the presence of free fluid in the abdomen. There are four areas to evaluate for free fluid by this view: the pleural space, the sub-diaphragmatic space, Morison's pouch (potential space between the liver and the right kidney) and the inferior pole of the kidney/paracolic gutter. The probe is placed on the patient at approximately the anterior to mid-axillary line, positioning the probe in the eighth to eleventh intercostal space and parallel to the ribs. Angle the

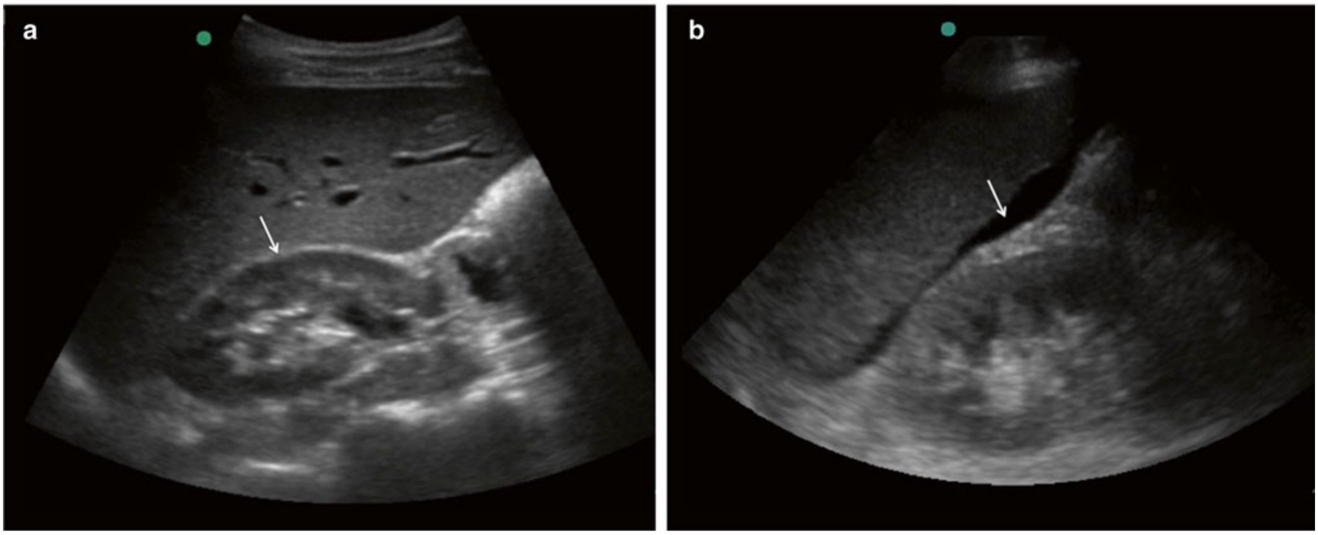

Fig. 21.2 *Right upper quadrant* (hepatorenal) view of the FAST examination. Normal examination (**a**) with a clearly visible hepatorenal interface (*arrow*) contrasted with a positive study (**b**) with anechoic fluid visible at the hepatorenal interface (*arrow*)

probe counterclockwise to minimize rib shadows if necessary. The probe indicator should be oriented towards the patient's head. Proper examination of the right upper quadrant should visualize the liver edge, the inferior pole of the right kidney, and Morison's Pouch (the potential space between the liver and the right kidney, or the hepatorenal space) (Fig. 21.2a). Land marking Morison's Pouch may be made easier by identifying the bright white fascia of the kidneys (Gerota's fascia) posteriorly. No single scanning approach will adequately visualize all of the four areas (mentioned in the aforementioned paragraphs) for free fluid and thus subcostal and intercostal approaches are necessary along with maneuvering the probe accordingly. The probe indicator in the subcostal window should point cranially and an effort should be made to scan in the midclavicular line as fluid is dependent. Right intercostal oblique and right coronal views may be used to evaluate for right pleural effusion, free fluid in Morison's pouch, and free fluid in the right paracolic gutter. The latter may be visualized by placing the transducer in the upper quadrant (coronal plane) and then sweeping it caudally from the inferior pole of the kidney. An awake and responsive patient may be coached on controlling their breathing to allow adequate visualization. Visualization of an anechoic (black) stripe between the liver and kidney (in Morrison's Pouch) or near the tip of the liver is considered a positive exam (Fig. 21.2b). Novice operators should bear in mind the following tips:

- The perinephric fat should be easily identified as it has an even thickness and is symmetric with the contralateral kidney; perinephric fat is a mimic for hematoma!
- The gallbladder, the small intestine, and the inferior vena cava are all mimics for free fluid; use Color/Doppler mode to exclude the presence of a vessel or scan the two-dimensional area of interest carefully and in the context of its neighboring structures.

LUQ View

Proceeding in a clockwise manner to the left upper quadrant, the spleen is used as a sonographic window to evaluate for free fluid in the following four areas: the pleural space, the sub-diaphragmatic space, the splenorenal recess, and the inferior pole of the kidney/paracolic gutter. The probe is placed on the posterior axillary line at the eighth or ninth intercostal space. Again, the probe indicator is pointed towards the patient's head and the probe may need to be rotated to minimize rib shadows. Examining the left upper quadrant requires visualization of the subphrenic and perisplenic spaces and the left kidney (Fig. 21.3a). The probe must be systematically swept, moved, or angled to visualize all three spaces. Usually the operator has to reach across the patient. The sonographer should sweep the probe usually more posterior and more cephalad than would be expected (think posterior!). The left intercostal oblique and left coronal views may be used to examine for left pleural effusion, free fluid in the subphrenic space and splenorenal recess, and free fluid in the left paracolic gutter. The spleen has a homogenous cortex, an echogenic capsule and hilum. Anechoic (black) blood may be seen between the spleen and kidney (Fig. 21.3b) or often above the spleen and just under the diaphragm with either of these findings being considered a positive test.

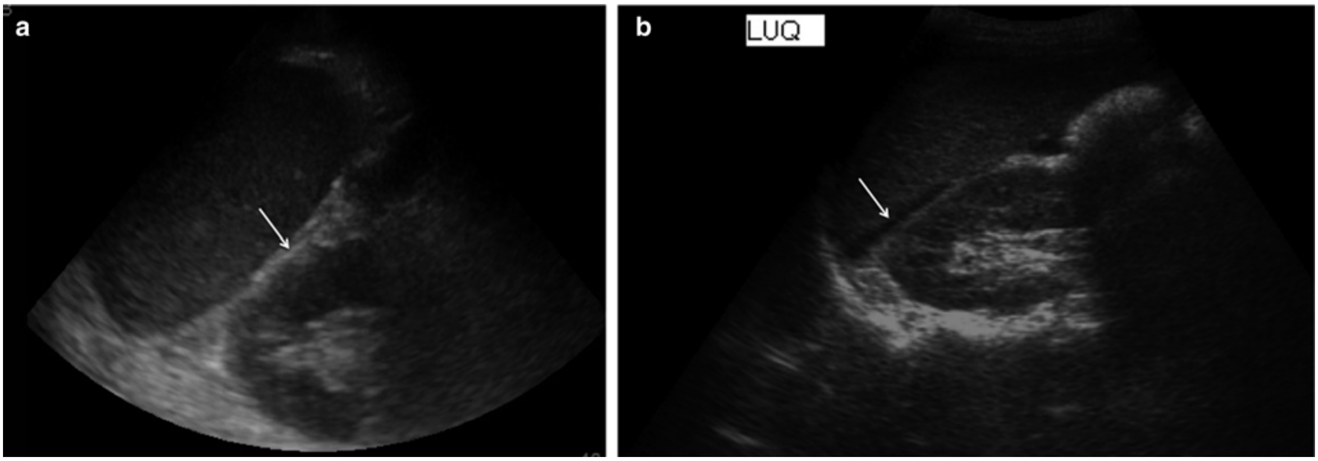

Fig. 21.3 *Left upper quadrant* (splenorenal) view of the FAST examination. Normal examination (**a**) with a clearly visible splenorenal interface (*arrow*) contrasted with a positive study (**b**) with anechoic fluid visible at the splenorenal interface (*arrow*)

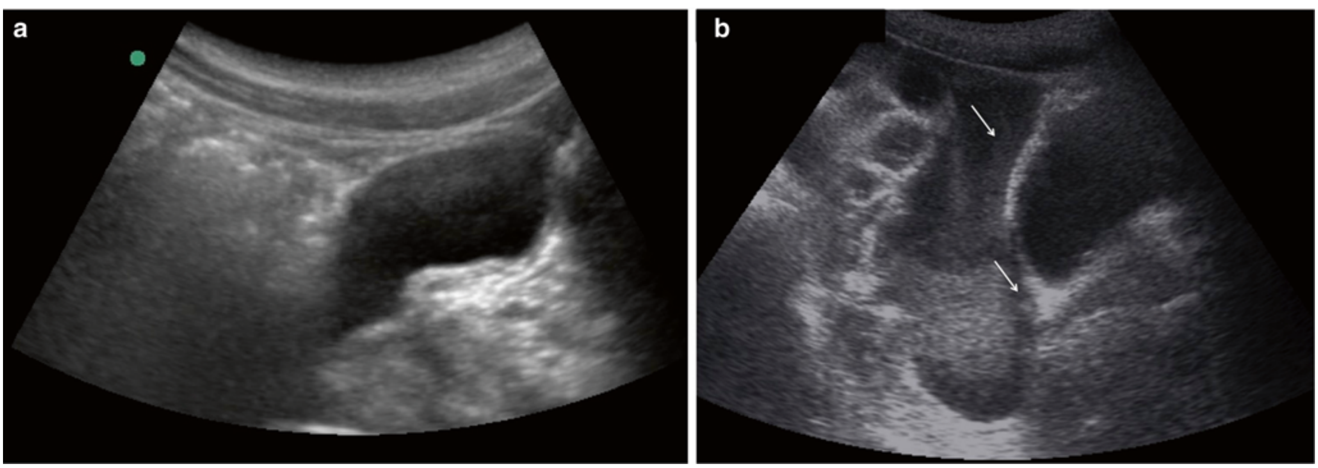

Fig. 21.4 Pelvic view of the FAST examination. Normal examination (**a**) contrasted with a positive study (**b**) with anechoic fluid visible in the retro-vesicular space (*arrow*)

Novice operators should bear in mind the following tips:

- Move the probe posteriorly; angle the probe with the ribs.
- Fluid-filled stomach, bowel loops and perinephric fat can all mimic free fluid; thus examine well the two-dimensional area of interest as mentioned in the RUQ view.

Pelvic View

The pelvic view is obtained by using the bladder as a sonographic window to evaluate for free fluid around the bladder (Fig. 21.4a). This is the most dependent part of the abdomen for free fluid accumulation; however the RUQ view remains the most sensitive view for free fluid detection. A high quality pelvic view is dependent on a full bladder, as an empty bladder limits the ability to detect small amounts of free fluid. Because most patients will have a urinary catheter inserted, the examiner may clamp this catheter or instill up to 200 cc of warm isotonic fluid for the purposes of completing an adequate study.

The pelvic view is obtained with a sagittal probe orientation, again orienting the marker towards the patient's head. The probe should be placed 2 cm superior to the symphysis pubis along the midline of the abdomen, while imaging on both transverse and longitudinal axis should be performed. The probe should be angled down until the prostate or vaginal stripe is identified. When the probe is angled further lower, the two-dimensional image formed will be inferior to the peritoneal reflection. The operator should sweep all planes of the bladder. The probe is swept from right to left or vice versa, paying attention to the retro-vesicular space in males and the retro-uterine space in females for the presence of anechoic (black) free fluid (Fig. 21.4b). As mentioned in previous paragraphs, the presence of anechoic fluid is considered a positive finding. Novice operators should bear in mind the following tips:

- In trauma patients the bladder is usually empty and thus clear visualization of the pelvis is often problematic.
- Fluid within a collapsed bladder, an ovarian cyst, seminal vesicles, and even the iliopsoas muscles can mimic free intraperitoneal fluid!
- Premenopausal women may normally have a small amount of free fluid in the pouch of Douglas.
- Reduce the two-dimensional gain for this exam as there is a good chance for observing a posterior enhancement artifact. (A hyperechoic region posterior to the bladder caused by transit of the ultrasound wave through a fluid filled bladder with only limited attenuation.)

When any of the aforementioned views is not clearly visualized, the exam must be scored "indeterminate" rather than negative. If any space in any view demonstrates free fluid, the exam must be scored "positive" regardless of the findings in other spaces, even if the examiner cannot visualize all spaces.

Uses

Blunt Abdominal Trauma

FAST is best studied in the context of blunt abdominal trauma. The Sonographic Outcomes Assessment Program (SOAP) trial, a prospective, randomized study concluded that FAST offered significant benefits including a 64 % reduced time to operative intervention, decreased numbers of Computed Tomography (CT) scans, a 27 % decrease in length of hospital stay, fewer complications, and a significant cost savings [2]. Investigation with FAST has been shown to significantly change management plans in 33 % of applications, including a 28 % reduction in CT scans, and an 89 % reduction in DPL performance [3].

One review compared the FAST to various examinations and investigations in blunt trauma patients, concluding that a positive FAST is better at detecting intra-abdominal injuries than exam findings of rebound tenderness, seatbelt signs, hypotension, abdominal distention, and guarding and also was better than adjunct investigations including reported base deficits, deranged liver enzymes, anemia, or an abnormal chest X-ray. The presence of free intraperitoneal fluid on bedside ultrasonography corresponds to a likelihood ratio of 30 that there is indeed an intraabdominal injury [4].

Perhaps the biggest advantage that FAST provides a Trauma Team Leader is its ready availability as a bedside tool. In circumstances of hemodynamic instability which would normally preclude CT scanning, the sensitivity of FAST is greatly increased. Sensitivity of ultrasound in the hypotensive trauma population approaches 100 % [5, 6]. Even when confronted with an unstable patient, sonographic examinations can be completed within 2–4 min [5, 7, 8]. Up to 90 % of patients with massive hemoperitoneum may be identified by examining only Morison's Pouch [6], with a mean examination time in one study of only 19 s for patients with positive findings [5].

The point-of-care nature of the FAST exam facilitates repeat exams. When confronted by a negative examination and no immediate indication for surgery repeating the FAST exam can be considered. Studies comparing the sensitivity of repeated FAST after a negative initial study have found that with time—and thus, with bleeding, an increased volume of intraperitoneal free fluid—sensitivity of the exam increases. Repeat examination is also useful in assessing GI injuries which are poorly detected by FAST, increasing the sensitivity of the study from 38 to 85 % when repeated in 12–24 h [9].

While FAST is most often associated with Level 1 trauma centers, the exam has a role in triaging the care of patients from peripheral centers to centers of definitive care. A patient requiring transfer to a trauma center with a positive FAST exam may, given the proper clinical context, be transported directly to an operating theatre which can be prepared in advance of the patient's arrival.

After considering the evidence, we are left with the conclusion that FAST in the blunt trauma population requires an assessment of hemodynamic stability as a decision point. As we discuss in the "Limitations" section, in the patient who is hemodynamically stable, other diagnostic modalities may yield more definitive diagnoses and subsequent management. FAST can be substituted for diagnostic peritoneal lavage in centers with ready access to an ultrasound device and like DPL [10], FAST serves to alter management primarily in the unstable patient. In a hypotensive population after blunt abdominal trauma, FAST was able to identify 97 % of patients with surgical injuries; in a subset of patients too unstable to undergo CT scanning, 64 % of patients with a positive FAST had surgical injuries whereas zero patients with a negative FAST had surgical injuries [11].

In summary, in the blunt trauma population FAST acutely changes surgical management only in the unstable population. In the stable population, FAST still has use as part of the ATLS Circulation assessment, for reassessment of a dynamically changing patient, and potentially for the triaging of inbound patients referred from non-trauma centers.

Penetrating Trauma

The role of FAST in penetrating injuries is somewhat lessened, as hollow organ injury does not necessarily present with hemoperitoneum and thus FAST is less sensitive in this population [12]. One particularly useful application, however, is to confirm or rule-out hemoperitoneum in cases of thoracoabdominal injuries for the purposes of surgical planning [13].

The most significant application of FAST in the penetrating trauma population is to rule out cardiac injuries. Though much of the evidence is derived from small studies, sensitivity of FAST to pericardial blood after penetrating chest trauma consistently approach 100 % [14–16]. Of patients with a positive pericardial FAST, the vast majority require surgical intervention [14]. In patients with a high clinical suspicion for cardiac injury, examination is rapid, with a mean time to examine the pericardium of under 1 min [17].

Limitations

The major limitations of FAST studies all pertain to its primary purpose: to detect free fluid. The purpose, in other words, is not to definitively diagnose all possible injuries. When considering the evidence surrounding the use of FAST exams it is important to consider the outcome variables for a given study. Outcomes of agreement with findings at laparotomy or agreement with CT scanning invariably demonstrate low sensitivity. CT scanning is far more sensitive for any injury which does not produce significant amounts of free fluid, such as hollow organ injury, retroperitoneal injury, or solid organ injury with minimal blood loss. The goal of a FAST exam is singular: to identify free fluid. Thus, when interpreting the data for or against the use of FAST, one must bear in mind the outcomes against which it is compared.

Critics of the FAST exam note that it is a poor single test for diagnosing the presence of an abdominal visceral injury. Using CT findings, we know that 34 % of patients with known visceral injuries have no appreciable hemoperitoneum [18]. Studies comparing FAST to CT scan or laparotomy findings have reported sensitivities ranging from 41 to 94 % [19–23]. When specifically considering sensitivity for hemoperitoneum FAST has a sensitivity of 91 %, considerably better than its sensitivity for detecting all injuries (69 %) [22].

Because we know that ultrasound may not detect all injuries, a negative FAST in a clinically deteriorating patient requires investigation or exploration. False-negative FAST exams—that is, studies failing to detect free fluid despite the presence of intraabdominal injury—often result in clinical deterioration. Such outcomes in blunt abdominal trauma require operative intervention in 27–37 % of cases [19, 20, 24] with a false-negative rate of 1.7–6.1 % [19, 20, 24]. This rate is higher still with penetrating injuries, where 24–100 % of false-negatives require operative intervention [13, 25] and false-negative rates increase to 9–29 % [13, 25, 26]. Therefore, while a negative FAST may be reassuring, further clinical deterioration *always* mandates further investigations (which may include a repeat FAST exam). Notably, patients with severe pelvic fractures are at increased risk of false-negative exams [27] and up to 19 % of true-positive exams in this population represent uroperitoneum rather than hemoperitoneum [28]. Whenever possible, hemodynamically stable patients without indications for urgent interventions should be investigated with cross-sectional imaging to rule out missed injuries.

The smallest amount of free fluid detectable by FAST exam varies by location of exam, and the origin of the fluid. For pelvic-originating free fluid to be visible in the left upper quadrant for example, fluid must have tracked up the right paracolic gutter, through the right upper quadrant and to the left upper quadrant, implying a significant volume of fluid even if the actual observed amount is quite small. Over 600 cc of pelvic fluid is required before it can be detected in the right upper quadrant [29], but in contrast, trace physiologic free fluid, ranging from 5 to 20 cc, is readily identified on pelvis views [30]. A small amount of visualized fluid does not necessarily represent a small amount of bleeding.

The presence of pelvic free fluid in reproductive-aged females is an oft-cited confounder of the FAST exam, but dismissing such findings is dangerous. Pelvic free fluid correlates to a tenfold increased risk of an intra-abdominal injury compared to the lack of free fluid, for both pregnant and non-pregnant patients [30]. Repeated ultrasonography in one cohort of pregnant females identified 100 % of patients with solid organ injuries [31], though the sample size was small. Still, we must recognize that fluid may be physiologic and not related to injuries. In female patients, fluid isolated to the anatomic cul-de-sac (Pouch of Douglas) is of traumatic origin only 1.8 % of the time, whereas 57.7 % of patients with upper-quadrant free fluid have injuries [32]. In this population, high clinical suspicion and a low threshold investigate is warranted.

Finally, all ultrasound investigations are limited by operator abilities. Because FAST, like all ultrasound techniques, depends on a single individual to perform the exam and interpret the results (typically in real-time) the quality of the test depends both on the operator's technical ability to capture images and also on the operator's ability to interpret them. Thus there are two main areas in which an individual operator's success rate may be negatively impacted.

One study investigating operator dependence assessed resident physicians and attending physicians in their reviews of prerecorded pericardial ultrasounds in penetrating trauma patients. Substantial differences in diagnostic specificity were found between residents and attending physicians (67 % versus 90 %) and those self-reporting minimal versus large experience with the ultrasound technique (65 % versus 93 %) [33]. Evidence of operator dependence also exists for the detection of hemoperitoneum. One attempt at assessing the FAST learning curve found that novice ultrasonographers have error rates of 17 % with incomplete exam rates of 25 %; after completing 25 studies, both rates decreased to 5 % [34]. The optimum number of studies needed to certify competence in FAST performance has not been defined in an evidence-based way, and credentialing requirements vary around the globe and by certifying organization.

Conclusions

The FAST examination is a powerful tool which can potentially change patient management when used as part of trauma resuscitation. The exam is rapid, provides management-changing information, does not significantly delay other tests or resuscitative efforts, and does not harm to the patient when performed without significant delay. A positive FAST examination, like a positive Diagnostic Peritoneal Lavage is an indication for laparotomy in the unstable or hypotensive patient. Negative examinations, which risk missed injuries, should always be followed with further investigations such as CT scanning in the stable population. Negative FAST investigations in the unstable trauma patient should prompt a rapid reassessment of the ATLS primary survey, but ultimately persistent hemodynamic instability may be an indication for exploratory surgery regardless of FAST results.

Rapid interpretation of FAST results allows the Trauma Team Leader to assess the patient's immediate needs and, when used appropriately, should not delay operative intervention or increase rates of missed injuries, and may significantly improve patient outcomes, time to operative intervention, and even costs of medical care.

Key Points

- Ultrasound is an important tool in the resuscitation of trauma patients; it contributes to but does not replace existing standards of resuscitation such as the clinical exam or ATLS surveys.
- A negative FAST exam is one where all four regions are thoroughly imaged and no fluid is seen; an indeterminate exam is one where all four regions cannot be adequately imaged.
- Any free fluid in any quadrant, even in an otherwise indeterminate exam, scores the FAST as positive.
- The sensitivity of ultrasound is diminished by inexperienced operators, obesity, COPD, excessive bowel gas, and some associated injuries; a negative exam in an unstable patient is *not* reassuring and warrants further investigation.

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Trauma Ultrasound: Beyond the FAST Examination

22

Michael Blaivas, Ashot E. Sargsyan, and Dimitrios Karakitsos

Introduction

Ultrasound in the evaluation of the trauma patient has moved far beyond the simple search for free fluid in the abdomen as a marker of intraperitoneal hemorrhage from solid organ injury. The modern clinician evaluating and treating a trauma patient employs ultrasound to search not only for blood in the abdomen but detect solid organ injury as well as trauma to the chest, head, and extremities. In fact, as ultrasound use grows by clinicians and they become familiar with more advanced musculoskeletal and vascular applications, a more extensive evaluation with ultrasound will become the norm rather than exception. In this chapter, we focus on advanced trauma ultrasound applications.

Trauma Ultrasound Development

The basis of advanced trauma ultrasound is still the original FAST application. Its history dates back to the 1980s and it was used successfully with good reliability by German trauma surgeons [1–3]. In time, the FAST examination migrated to North America where, despite competing with computed tomography, it spread widely among trauma surgeons and emergency physicians who used it to evaluate first blunt and then penetrating trauma patients. Eventually, it replaced the diagnostic peritoneal lavage (DPL) [4, 5] except for certain rare circumstances (DPL and its current role is discussed further in Chap. 17). While initially compared to clinical outcome in Germany, which yielded extremely high sensitivity and specificity, the FAST examination revealed potential pitfalls when compared to computed tomography. These included missed liver and splenic injuries which did not hemorrhage into the peritoneal cavity [6–9].

Initially excluded from the patient group evaluated with a FAST examination, penetrating cardiac injuries have been well studied in trauma patients, and without question, ultrasound can deliver rapid and critical diagnosis when it reveals the presence of pericardial effusion [10, 11]. Further, impending hemodynamic compromise may be diagnosed when evidence of early tamponade is suspected due to right atrial and ventricular free wall movement or collapse. An early study by Plummer documented the impact of cardiac ultrasound as part of the FAST examination in averting patient deaths from unsuspected pericardial effusion and tamponade [11]. The authors noted a decrease from 50 to 0 % mortality in patients when comparing those presenting prior to ultrasound use and after. Rozycki performed a large-scale study of trauma surgeons evaluating for pericardial effusion in cases of penetrating trauma [10]. The investigators reported that trauma surgeons accurately diagnosed pericardial effusions from penetrating cardiac injury.

Despite the large number of studies from radiology, trauma surgery, and emergency medicine researchers, there was a paucity of data that utilizing ultrasound in the care of the traumatized patient improved outcome, decreased cost or mortality. A study by Melniker et al., despite small size, accurately documented the impact of the FAST examination on traumatized patient care [12]. The authors found that time to operative care was 64 % less for patients receiving a FAST exam compared to control patients who did not. FAST

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patients underwent fewer CTs with an odds ratio of 0.16. They also spent 27 % fewer days in the hospital and had fewer complications (odds ratio 0.16). Finally, of critical importance for the modern health-care economies, FAST patients had lower hospital charges that were 35 % less compared to control or non-FAST patients.

The Fast Examination in Critical Review

The FAST has seen its fair share of controversy with questions about sensitivity, specificity, as well as utility in the modern computed tomography-driven trauma assessment [13, 14]. A Cochrane review of trauma ultrasound in 2013 evaluated the impact of the FAST examination on trauma patient outcomes [15]. Despite the poorly performed study, it raised important questions about ultrasound in abdominal trauma and suggested not only that better designed studies are needed, but there is a requirement for more research documenting the impact of ultrasound in abdominal trauma. In addition, various non-trauma pathologies, such as preexisting ascites, acute intra-abdominal infections with and without gastrointestinal perforation, cancer perforations, sterile serositis (e.g., from familial Mediterranean fever or connective tissue disease), etc., may result in the acute or subacute accumulation of liquid matter in the abdominal cavity, which in turn may render the patient FAST positive. Many of these fluid collections will be small or even trace fluid amounts and ascites from liver cirrhosis are often found with particular findings allowing identification as to the underlying cause. Despite this, interpretation of FAST findings should always be performed with caution by physicians and in the clinical context of the individual case scenario. Rapid, sterile fluid sampling, either via formal DPL or via a simpler diagnostic peritoneal aspirate (DPA), may be still useful in this setting.

Ultrasound Equipment and Settings

The standard ultrasound equipment required for a FAST examination is quite simple as much of the latter can be performed with just one transducer. The curved abdominal transducer with a frequency range of 2–5 MHz is commonly utilized; however, it is severely limited in cardiac imaging and a phased array or micro-convex transducer may be needed in patients who are obese or have other comorbidities [16]. Ideally, the operator will have a modern ultrasound machine with good imaging capability and adequate penetration for the rapidly growing proportion of obese patients in the developed world. A machine that allows rapid, one-touch changes in ultrasound transducer selection is important. Additionally, the optimal ultrasound unit not only requires a short boot-up time (less than 15 s), but the time required for a new transducer to be ready to scan upon switching has to be very short (less than 5 s). Documentation capability is critical and digital video loops should be stored on the machine. Ideally there would be capability to annotate and export loops for later review and integration into the medical record. A micro-convex transducer has a narrow footprint allowing easier cardiac imaging, especially if the traditional subxiphoid window does not yield adequate results. However, it also provides worse resolution for the abdominal portion of the examination when compared to a typical curved abdominal transducer. Thus, many established programs and experienced individuals prefer to have more than one transducer at their disposal including a curved abdominal and phased array.

Additional Ultrasound Applications in Trauma

Additional Equipment and Views

The additional applications involved in trauma ultrasound examination essentially mandate a linear array transducer. While a curved array can be used as well as a micro-convex or phased array, most sonographers will quickly grow frustrated with the image resolution and difficulty in interpretation. The linear array transducer will allow for required high resolution in the near field of several applications. Apart from two-dimensional imaging, the application of various other modes such as M-mode and color and power Doppler is important.

Pleural Effusion

The simplest extension of the basic FAST is the additional views acquired while performing an examination of the right and left upper quadrants. As mentioned previously, a focused look at the dome of the liver, spleen, and diaphragms is a critical portion of the modern FAST examination. That same view affords the ability to detect fluid in the right or left hemithorax. Studies suggest as little as 25 cc of fluid may be detected [17]. While the clinical significance of such a small collection is questionable, the ability to detect fluid more accurately than plane radiograph is an important tool [18]. Fluid will appear as anechoic, or dark, with the typical stipulation that coagulating blood will be more echogenic. The lung may be seen moving in the fluid (Fig. 22.1). Best imaged with a phased array transducer when scanning through ribs posteriorly, most sonographers simply pan their curved abdominal transducer ultrasound beam more cephalad and make sure to include the diaphragm on both the left and right side.

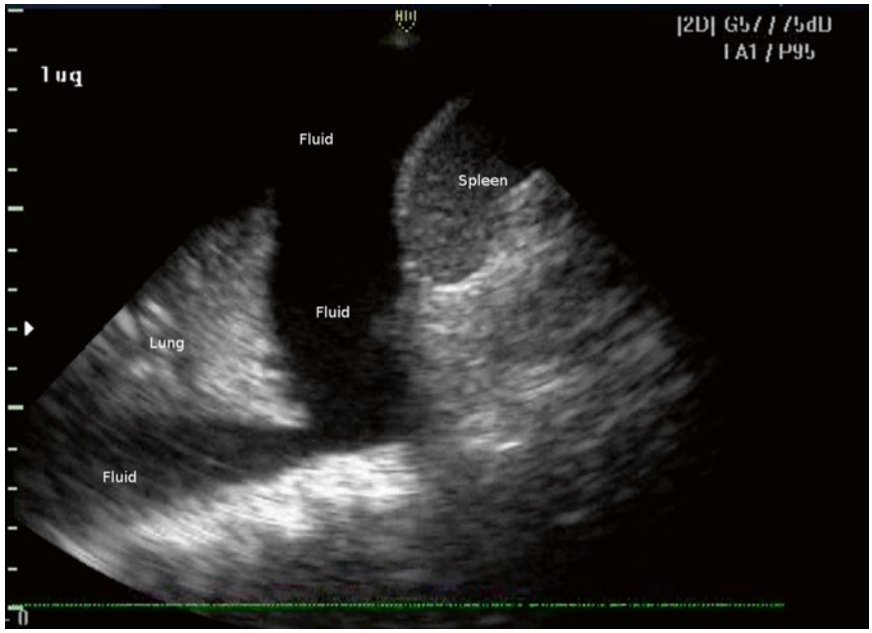

Fig. 22.1 Dark or anechoic fluid surrounds the relatively echogenic lung

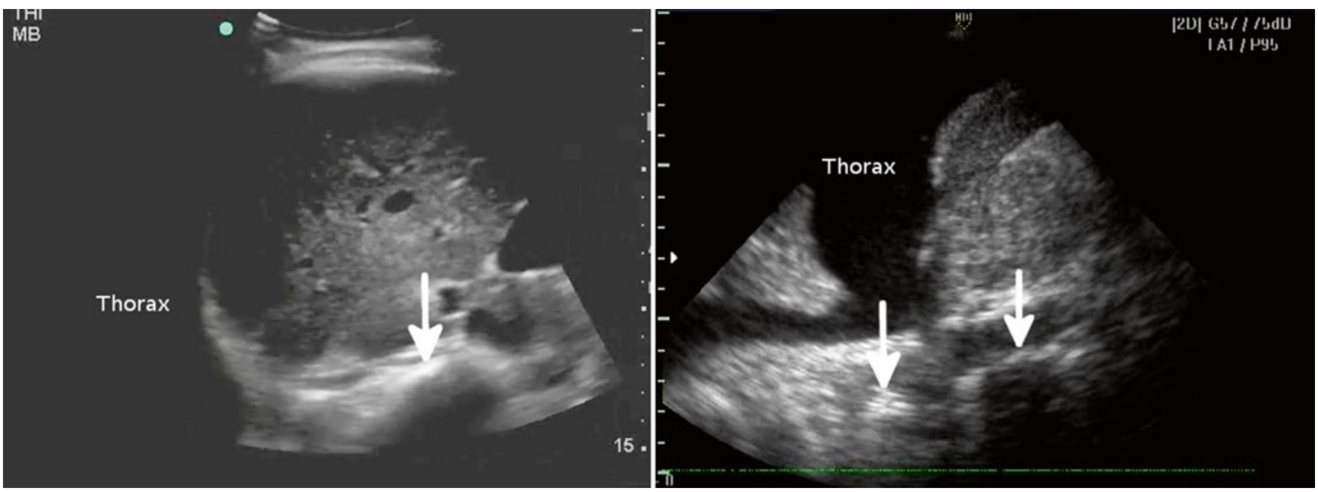

Fig. 22.2 The *left image* shows an ultrasound with no fluid in the chest; the spine seems to end at the diaphragm and cannot be traced further (*arrow*). The *right image* shows a collection of fluid in the chest, with the spine continuing above the diaphragm (*arrows*)

A helpful sign that brings the novice's attention to fluid in the chest is looking for the spine above the diaphragm [19]. Typically not noted without a good acoustic window, which is provided by fluid in the chest, it is an obvious sign that fluid is present in the chest (Fig. 22.2). This is more important than ever because modern equipment can eliminate echoes typically seen above the diaphragm to such an extent as to leave a dark, anechoic area above the hemidiaphragm when no fluid is present. The volume of an effusion can even be roughly estimated using one of several simple methods [20, 21]. A hemothorax can be followed for changes in size and moderate increases should be obvious.

Pneumothorax

One of the most popular and clinically useful advanced trauma ultrasound applications is the detection and exclusion of pneumothorax. The basis for this application is that ultrasound can detect the back-and-forth movement of the visceral and parietal pleura occurring during lung expansion and contraction, something that should be present in spontaneously breathing and ventilated patients. While ultrasound does not detail lung parenchyma in the healthy lung, it does show the pleural line, without distinguishing visceral from parietal pleura (Fig. 22.3). In order to visualize the

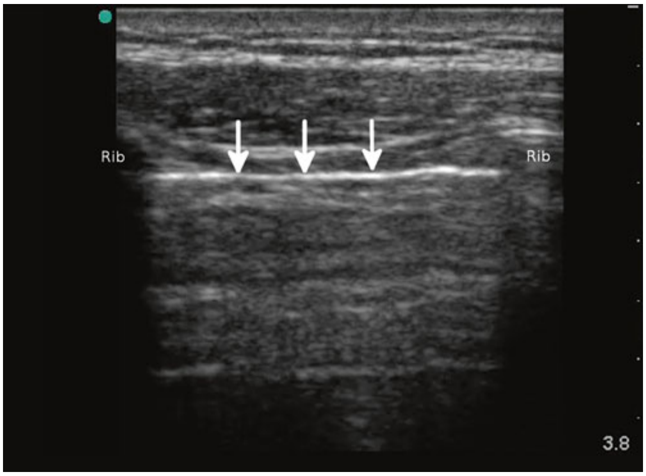

Fig. 22.3 The *white line* (*arrows*) in between the ribs is the pleural line; the visceral and parietal pleura cannot be distinguished

movement of the layers past each other, known as the sliding lung sign (SLS), both the visceral and parietal pleura must be imaged. However, when air is present between the layers as in the case of a pneumothorax, it blocks diagnostic ultrasound from imaging the visceral pleura since medical ultrasound is not transmitted through air [22, 23]. Thus, when air is present between the visceral and parietal pleura, ultrasound shows loss of the sliding lung sign. Confirmation of lung sliding can be verified using M-mode. The area under investigation, between the rib shadows, is centered in the screen, while M-mode is initiated after aligning the vertical line through the area in question. The "barcode sign" or "stratosphere sign" is the appearance of parallel horizontal lines extending through the entire field in view, which indicates the lack of normal motion of an inflated lung on M-mode (Fig. 22.4). While the lack of lung sliding is not specific for pneumothorax, the presence of the lung sliding sign effectively rules out pneumothorax at the intercostal locations under the applied ultrasound probe. The sensitivity and specificity of this sign has varied significantly in multiple studies. Reported values have ranged from 40 to 99 % and 60 to 100 % for sensitivity and specificity, respectively [24–28].

The lung ultrasound examination was traditionally performed using a rudimentary micro-convex transducer [29]. However, modern lung ultrasound for evaluation of pneumothorax is best performed using a high-resolution linear ultrasound transducer. Such a transducer allows the high-resolution imaging of the pleural interface and enables the sonographer to detect the subtle sliding of the pleural surfaces. Improved imaging can lead to higher confidence when such movement is absent, a problem with earlier ultrasound probes. In the trauma patient, the intrathoracic air will seek the least gravitationally dependent area in the chest. Therefore, if the patient is supine, it should be in the anterior chest. Both sides

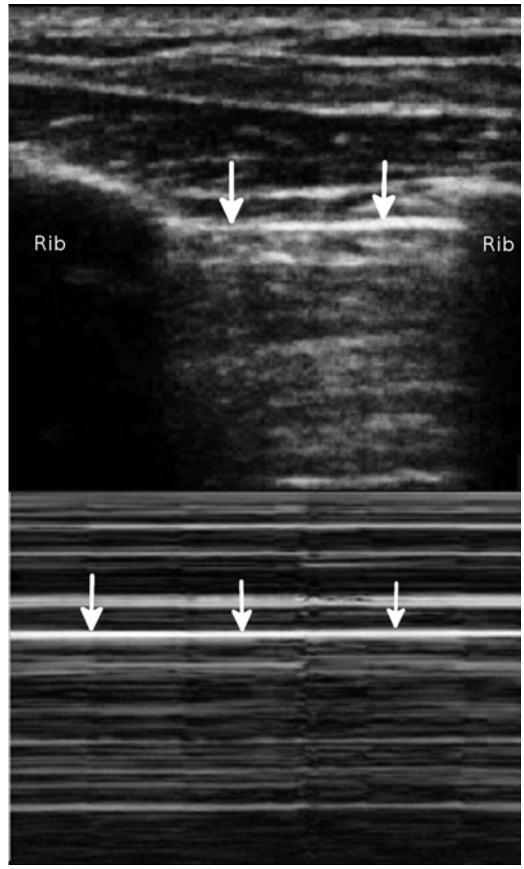

Fig. 22.4 The stratosphere or barcode sign. No movement occurs above or below the pleural line on the M-mode tracing as signified by the identical appearance above and below the pleural line (*arrows*). This occurs as a result of the pneumothorax preventing visualization of the visceral pleura

of the chest should be evaluated. The ultrasound transducer is placed in a sagittal orientation with the indicator pointed cephalad. This allows one to use the ribs as an anatomic landmark (Fig. 22.5). This is important since multiple tissue lines may be present that simulate a pleural line and could be confusing. The pleural line will be just deep to the ribs as noted. In the normal lung, it will be seen moving back and forth, typically disappearing under the bony ribs. This movement will be timed to respirations, not the heart rate. When the lung sliding appears to be stunted, but still present (sometimes described as shimmering), and is timed to the heart rate, it is likely a lung pulse [30]. The lung pulse occurs when no pneumothorax is present to introduce air in between the visceral and parietal pleura. However, if the lung is not ventilated, such as in a misplaced endotracheal tube, the pleural line will appear to pulse, not moving significantly, in time with the heart. The identification of a lung pulse can be coupled with simple deductive reasoning to decide if a main-stem or esophageal intubation is present. If seen unilaterally, a lung pulse should indicate ipsilateral main-stem bronchus intubation or obstruction such as mucous plugging [31].

Fig. 22.5 The ultrasound transducer is in a cephalad orientation resulting in a sagittal scanning plane

Absence bilaterally suggests an esophageal intubation or tracheal obstruction. Appropriate correction such as slowly pulling back the endotracheal tube in a main-stem intubation can be tracked in real time by observing the disappearance of a unilateral lung pulse as the tube is pulled back.

While pleural line sliding may be absent not only in cases of pneumothorax, given a clinical setting where PTX is high in the differential, an absent SLS may be critical for clinical decision-making. Pathologic processes that may eliminate the SLS also include pneumonia; COPD, especially bullae formation; and others. A near pathognomonic finding for PTX is the lung point [32]. The lung point is literally the intersection of normal lung with free intrathoracic air or PTX. Additionally, other artifacts from the pleura such as echogenic B lines may be seen sliding in and out as the normal lung moves in and out of view [32]. While several pitfalls with this finding can be seen to include the edge of the heart, diaphragm, and contused lung, careful scanning and awareness of nearby anatomy make this sign almost 100 % specific [33]. It is important to note that as a PTX increases in size, the lung point will become more lateral and posterior in a supine patient and then disappear completely as no visceral pleura can be seen contacting the parietal pleura anywhere along the thoracic wall (Fig. 22.6).

Resuscitation and Volume Status

Adding a view of the inferior vena cava to the cardiac assessment allows the operator to assess patient volume status and potentially rates of blood loss [34–38]. While not without controversy, since the IVC diameter and collapsibility are well-proven monitors of volume status in its extremes (such as significant collapse or greater than 2 cm dilation with no variation), it is a reasonable adjunct in the trauma patient. Studies of dehydrated or volume-depleted patients have shown that an IVC that collapses completely with normal respiration is an indicator of low intravascular volume and also low central venous pressure (Fig. 22.7). Inversely, a dilated, non-varying IVC that is greater than 2 cm in diameter measured 2 cm distal to the confluence of the hepatic veins into the IVC suggests fluid overload and increased central venous pressures. In trauma patients, it is the flat, completely collapsing IVC that is likely to be of greatest concern. This is especially useful in cases where blood loss may be suspected but cannot be proven in an unstable patient. One study suggested that as little as 450 cc of blood removed over 5 min may be detected by serial IVC measurements [38]. However, other studies have called this into question [39]. None of the studies, either pro or con, have had the power to settle the argument [40]. However, the principle is potentially useful. One should be cautious, however, as this assessment may become less accurate in patients on positive pressure ventilation as the elevated intrathoracic pressures may mask the IVC variability.

Musculoskeletal Ultrasound

In terms of clinical logistics, our research group has recently launched the holistic approach (HOLA) concept of critical care ultrasound (CCU) imaging. We have envisioned HOLA-CCU as part of the patient examination by a clinician to visualize all or any parts of the body, tissues, organs, and systems in their live, anatomically and functionally interconnected state and in the context of the whole patient's clinical circumstances [40]. In that sense, any ultrasound view obtained through the skin contains some information about soft tissues. While serving as imaging window and anatomical reference structures in focused techniques (e.g., the chest wall in lung scanning), soft tissues themselves are often a primary target (e.g., in extremity injury). This is particularly true regarding musculoskeletal (MSK) ultrasound scanning [41, 42]. Ultrasound in MSK evaluation is well established and not surprisingly has been adopted for trauma patient evaluation as well. High-resolution ultrasound imaging through the use of linear array transducers allows a detailed look at the cortex of long bones, ribs, and other structures. Since nearly all fractures should involve some sort of cortical disruption, a highly magnified look at the cortex is ideal for detecting fractures. In trauma cases, some of the long bones sought may be quite deep and curved abdominal transducers may need to be utilized to image the femur, especially in large patients. Already present at the patient bedside, ultrasound allows detection of fractures such as the one seen here in the femoral shaft of a motor vehicle accident patient (Fig. 22.8).

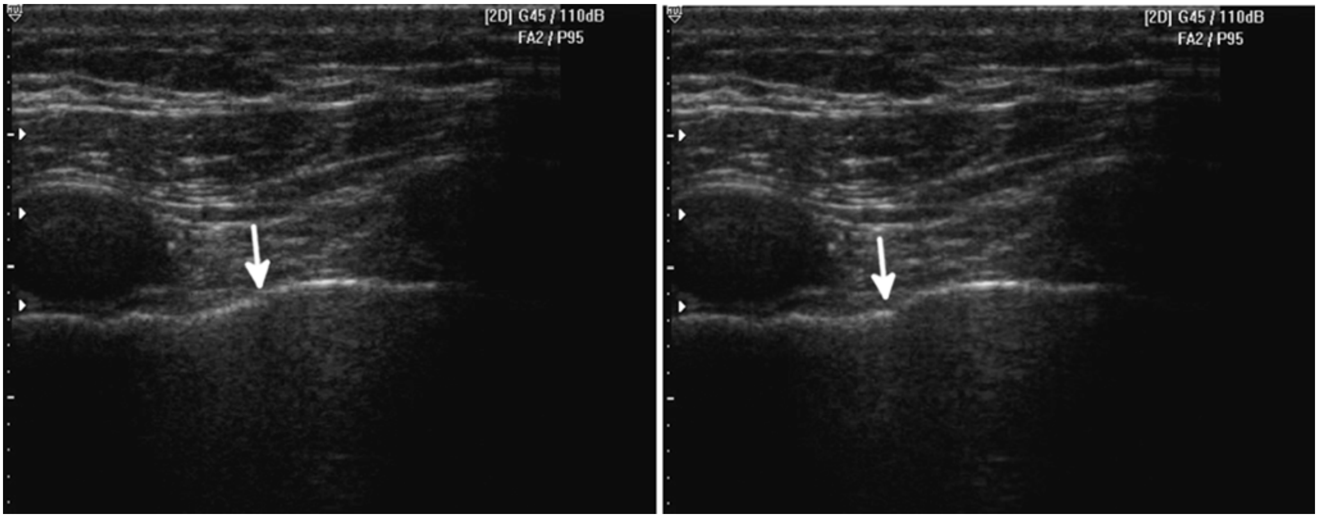

Fig. 22.6 A lung point is demonstrated, with pleural sliding and aerated lung on the left side of the screen and the beginning of the pneumothorax or intrapleural air on the right. The *left image* lung point is in a different location than the *right image* (*arrow* depicts its leading edge). The lung point location changes with respiration

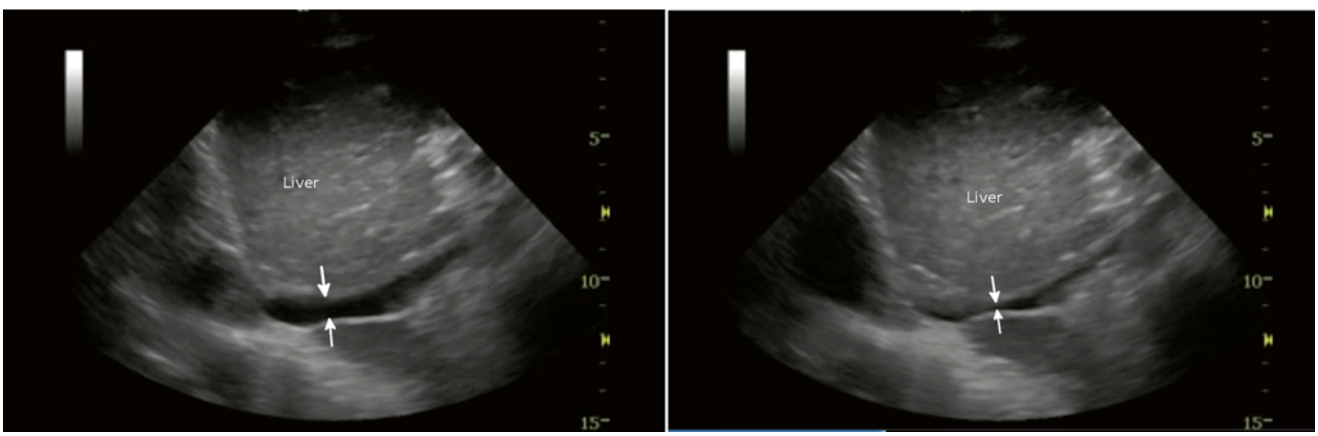

Fig. 22.7 The *left image* shows an IVC prior to a normal inspiration; it does not appear significantly collapsed (*arrows*). The *right image* shows a significant collapse of the IVC with respiration. With deep breath, the IVC could not be visualized due to flattening

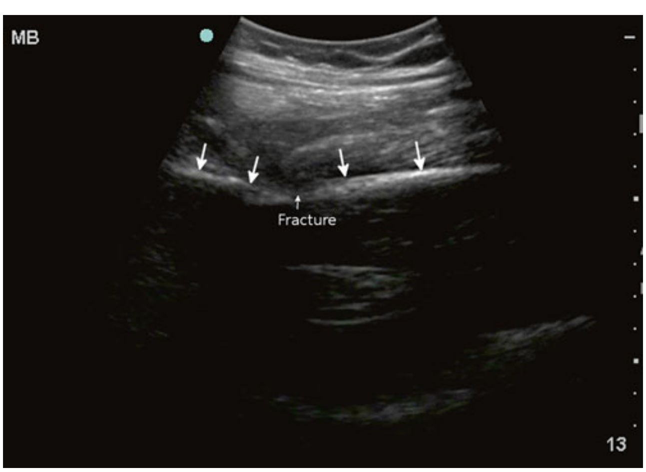

Fig. 22.8 A disruption is seen in the cortical continuity of the femur in this femoral shaft fracture. Notice the change in angle (*arrows*) of the femoral shaft

Bony cortex is seen as a bright echogenic line, typically linear. The ultrasound examination should be performed in at least two orthogonal planes as with any organ of interest. Especially with bones such as the radius and ulna, one axis may appear grossly normal, while the orthogonal one shows a step-off, suggesting a fracture that can be investigated more closely. Typically a long bone is imaged in its longitudinal and transverse axes. In the short axis, a long bone such as the humerus or femur will be curved while the tibia will be relatively flat. The key is to focus on any cortical disruptions. The operator must take the patient's age into account and avoid mistaking growth plate regions for fractures. One of the single most useful aspects about MSK ultrasound is that a normal comparison is almost always readily available in the form of the contralateral limb or side of the torso. Apart from bone pathology, ultrasound has the potential to detect muscle, tendon, and soft tissue pathology in trauma victims. Acute muscle contusion and hemorrhage appear hyperechoic, while later stages of injury exhibit mixed patterns. Partial or complete musculotendinous tears with or without retraction are usually obvious. Intramuscular hematomas may later evolve into seromas or intramuscular cysts (anechoic fluid collections) that may require aspiration or surgical drainage. Hypoechoic muscular swelling with architectural disorganization may be observed in traumatic rhabdomyolysis.

In crush injuries, ultrasound can assist in critical decision-making and have extremity and lifesaving significance, since a buildup of pressure within the fascial compartment disrupts tissue perfusion (compartment syndrome) with dire consequences, unless fasciotomy is emergently performed. An advanced HOLA protocol in extremity crush injuries could include assessment of: (a) the shape and structure of all the fascial compartments (looking for outward convexity of the normally flat fascial partitions between compartments), fractures, tears, hematomas, and hypoechoic areas of potential fluid collection or necrosis; (b) color and pulsed-wave Doppler monitoring of the vessels within the compartment and the main artery feeding the compartment; (c) renal imaging (monitoring of size/volume, renal arterial spectral Doppler, and parenchymal differentiation); and (d) search for free abdominal fluid if the thigh and pelvis areas are involved.

Head Trauma

Ultrasound in head trauma offers surprising utility. The same MSK applications described above apply to the skull and remarkable detail can be noted such as small disruptions in the smooth bony cortex. Any disruption in the cortex or step-off may be a skull fracture line. Evaluation in two orthogonal planes will help better define the area in question. Suture lines are a potential for confusion but some practice like scanning the normal skull will help the sonologist to become familiar with their appearance. Additionally, most skull fractures will be associated with an overlying soft tissue hematoma [43]. In children, suture lines, especially partially closed ones and fontanels, may present additional challenges. However, known anatomic locations and the ability to trace the suture line and evaluate any skull fractures in two orthogonal planes allow one to differentiate between a traumatic injury and normal anatomy. Facial fractures can also be detected using a linear array transducer but require more experience. Again, the sonologist looks for cortical disruptions of facial bones and compares the injured and uninjured side whenever possible. The ultrasound literature contains studies documenting ultrasound's high accuracy in the evaluation of the sinuses and blood-filled sinuses, orbital air, and a multitude of other injuries that can be diagnosed with sufficient skill [44–46].

There is additional utility to ultrasound in estimating and tracking the intracranial pressure (ICP). While direct visualization of brain injury in the adult is rarely possible with ultrasound, a secondary marker of significant (although sometimes still nonoperative) brain injury is the elevation in the ICP. When significant brain injury results from trauma, it is typically associated with some level of elevation in ICP. With a large intracranial hemorrhage, this may be a marked elevation, while with a smaller one, the elevation is relatively minor. Dating back to the 1960s, researchers realized the spinal fluid bathing the optic nerve inside the optic nerve sheath communicated directly with the ventricles [47]. Any rise in ICP from the ventricles was noted almost instantaneously in the optic nerve sheath. Being a distensible structure, the sheath dilates in a somewhat predictable fashion. Multiple studies have evaluated the utility of measuring the optic nerve sheath diameter (ONSD) in trauma and other patients [48]. The main challenges are careful technique and interoperator reliability. Due to the relatively small size changes involved, precise measurements are required. However, a recent meta-analysis suggested ONSD measurement had utility in predicting elevated ICP and in trauma suggesting intracranial injury [49]. While CT may be the common test of choice in most trauma settings, it is not ubiquitously available in all locations and is very expensive. During transport and for serial monitoring, ONSD measurement through ocular ultrasound holds considerable promise and utility in the right clinical context until other technologies are developed that are also noninvasive and affordable but largely user independent.

To perform an ONSD measurement, a linear ultrasound transducer is the probe of choice and the scan is performed through a closed lid. Both eyes should be scanned when possible for comparison. A large amount of gel is placed in the orbit for good coupling but also to avoid any pressure on the eye. In the ideal technique, the ultrasound screen will show an obvious anechoic stripe at the top of the screen signifying the presence of gel between the transducer and the eyelid. While sophisticated equipment may be able to measure some transmission of pressure through ultrasound gel, it is not of any physical significance. Sterile gel can be used and is widely available in small lubricant packets in clinical settings. Wiping off the gel has to occur with great care to avoid pressing on the globe if ocular injury is suspected or noted on ultrasound. As an aside, ultrasound is superb at detecting several ocular injuries such as lens displacement, globe rupture, retinal detachments, and vitreous bleeding. However, the optic nerve is the goal of this examination and is visualized just posterior to the globe. The ideal for simple measurement of the ONSD is to obtain a clear image of the optic nerve as it travels posterior from

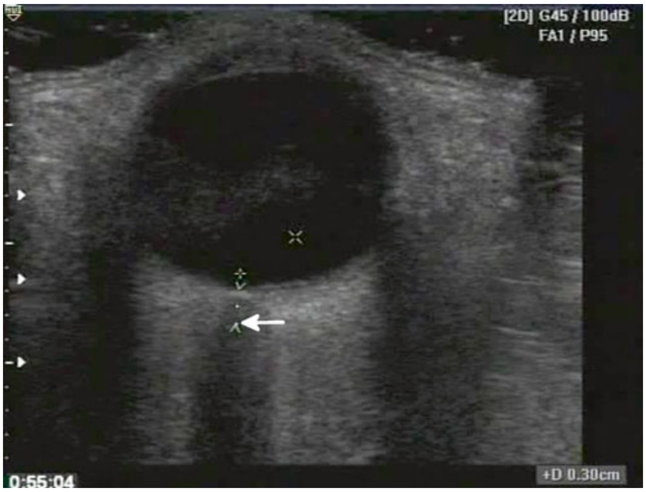

Fig. 22.9 A normal optic nerve sheath diameter is seen. The transverse measurement should be taken at a location 3 mm posterior to the globe (*arrow*)

the globe. Measured at approximately 3 mm posterior to the globe, the internal diameter should be obtained several times and averaged (Fig. 22.9). A meta-analysis suggested that using a cutoff value around 5.8 mm may be reasonable [49]. Our group has recently suggested new quality criteria for sonographic ONSD measurements which are summarized below:

- ONSD measurement should not be made through the lens.
- Sonographic differentiation between the nerve proper and the arachnoid (CSF space) must be obvious.
- The outer border of the arachnoid must be identifiable for actual ONSD measurement; clear, well-focused images must thus allow confident measurement of the inner diameter of the dural sheath.
- Ideal views of the optic nerve demonstrate the point of its penetration into the globe.
- Good views offer opportunities for additional information potentially useful with growing experience, such as tortuosity of the nerve, hypo-echogenicity of the arachnoid, its irregularity due to distention of CSF-containing "cells," etc.
- Correct standardized measurements: since the most distensible portion of the sheath is at the 3–4 mm distance from the vitreoretinal interface, measurements should be performed at this level in a direction perpendicular to the axis of the nerve. In extreme gaze deviations, this may be difficult to achieve due to the acute angle between the nerve axis and the posterior wall of the globe.
- It is highly recommended to measure ONSD bilaterally and in more than one image frame.
- For ONSD trend monitoring, the previous record with images must be reviewed to ensure similar views and measurement technique [50].

Contrast-Enhanced Ultrasound

One of the most significant limitations to trauma ultrasound is a relative insensitivity to solid organ injury detection when free fluid in the abdomen is absent. While such liver and spleen fractures may not be as immediately threatening, they do pose potential for morbidity and even mortality and should not go undetected. Ultrasound contrast, while still not approved for use in the United States for body imaging, is widely used in the rest of the world. Studies have indicated that trauma team members can rapidly perform FAST examinations with ultrasound contrast use and one dose of agent may last long enough for the examination to be completed. The contrast could be seen even with a rudimentary ultrasound machine. More recent literature has suggested an impressive sensitivity and specificity of ultrasound for solid organ detection when used with contrast. While still lagging behind the gold standard of computed tomography, contrast-enhanced ultrasound is much less expensive and delivers no ionizing radiation.

Although contrast agents vary in their length of effect and phases, in general the liver and spleen appear to glow actively after contrast agent injection (Fig. 22.10). An area of hematoma or lack of active perfusion is outlined by surrounding contrast-enhanced tissue. Similarly, active bleeding may be denoted by a concentration or pooling of contrast agent in some cases. Delayed phases of some contrast agents as they are being absorbed by cells in the liver or spleen may further outline the area of hematoma or even active bleeding. One group from Italy reported a sensitivity of 91.4 % and a specificity of 100 % in a group of 32 traumatized patients, stating that it was almost as sensitive as CT [51]. Clearly the future for contrast-enhanced trauma ultrasound is potentially bright and appears to be largely unwritten. However, with the increased realization of the dangers of medical ionizing radiation from CT and this technology's overuse and expense to health-care systems, contrast ultrasound will likely see further development and utilization.

Future Directions in Trauma Ultrasound

It is likely that the future of trauma ultrasound will heavily involve not only contrast agent utilization as suggested above but also utilization of three-dimensional imaging. Several studies have suggested the utility of 3D ultrasound imaging in trauma. When applied to other disease processes, 3D ultrasound has revolutionized pelvic organ evaluation as well as studies of the liver. Vascular ultrasound is benefiting from 3D technology and other sectors of ultrasound are likely to follow. The ability to image an organ or section of the organ in three dimensions is critical in the overall evaluation of its architecture and function. The severity of injury or size of a hematoma in a liver may be better detailed and the tract and damage from a projectile in a leg may be traced and potential for damage to nearby vital structures fully appreciated.

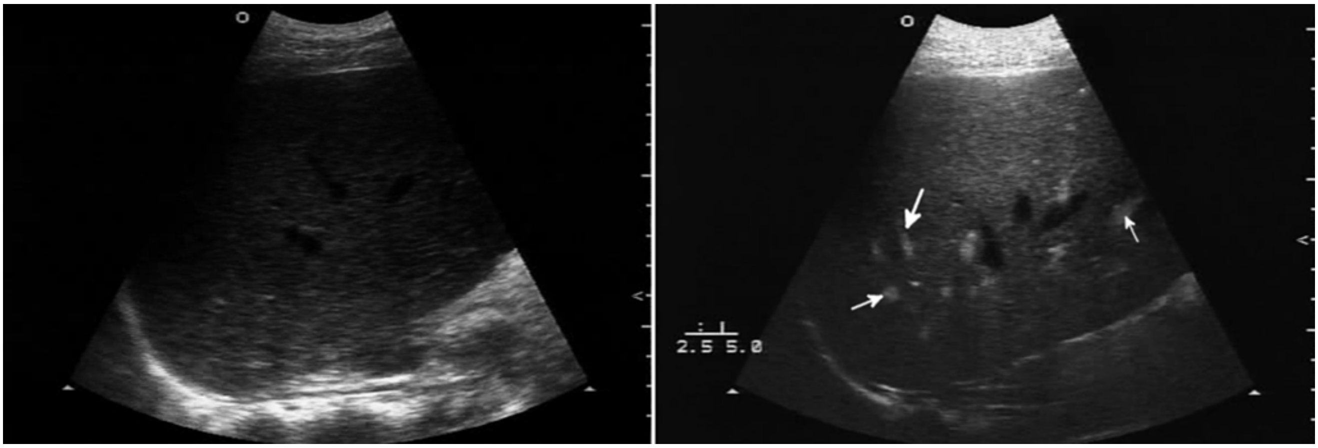

Fig. 22.10 Contrast material is seen appearing in the liver on the right image (*arrows*); prior to contrast, the liver on the left lacked the glow provided by the intravenous contrast agent

Conclusions

Advanced trauma ultrasound applications allow the clinician to evaluate for more pathology than ever thought possible when the FAST examination was first created. In fact, it is evolving into a head-to-toe-focused diagnostic imaging evaluation. In the future, trauma ultrasound is likely to further be enhanced by newly developed and upcoming technology. The expansion beyond the basic FAST is inevitable given the multiple challenges health-care systems face around the world and the efficiency and accuracy ultrasound presents at the patients' bedside.

Key Points

- The FAST examination lacks sensitivity for solid organ injury without intraperitoneal hemorrhage.
- Evaluation for blood in the thorax is a simple modification of the typical FAST examination.
- A linear transducer is important for evaluation of long bone injury, pneumothorax, and elevation in intracranial pressure.
- Sonologists should practice and become familiar with advanced techniques prior to attempting these applications on actual trauma patients as several require additional experience and expertise.
- Technical advances in other ultrasound fields continue to filter down into trauma ultrasound and expand its utility including through contrast-enhanced evaluation of solid organ injury and three-dimensional evaluation of hemorrhage.

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Telemedicine and Future Innovations

23

Corry Jeb Kucik and J. Jonas Carmichael

…and yet a true creator is necessity, which is the mother of our invention.

–Plato, The Republic, Book II, 369c.

Introduction: The Need

Trauma remains a leading cause of death and disability throughout the world, including in developed nations. Despite the rigorous construction of advanced trauma systems throughout the USA, regional differences persist, and can be exacerbated by supply and geography constraints. Mismatches exist between the incidence of trauma throughout the USA and the number of traumatologists, Level 1 trauma centers, or even adequate community hospitals existing to service this need (Fig. 23.1). Due to multiple reasons (costs, inability to recruit and retain clinicians, rarity of certain types of trauma) there may never be a day that enough fully staffed and qualified centers will exist to enhance care in austere locations. Further, the "tyranny of distance" imposed not only on rural locations but also on special populations (e.g., correctional facilities, home health care settings, nursing homes, military populations overseas or at sea, cruise ship passengers) can never be fully alleviated by the construction of US trauma centers, exacerbating the shortfall all the more.

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The Promise of Innovation and Telemedicine

Bridges to the future are needed not only to service this great need of trauma care, but perhaps, in time and with game-changing technologies, to prevent and obviate it. The use of the word "innovation" is common in medicine today, where everyone from startup companies to the boards of established companies ceaselessly search to profit from the next "big thing" in medicine. Telemedicine, the delivery of health care and the exchange of health-care information across distances, holds particular promise in trauma care, particularly when existing limitations (supply, distance, etc.) render it either more acceptable than existing conventional services or indeed the only option available.

Telemedicine is defined by the Telemedicine Information Exchange (1997) as the "use of electronic signals to transfer medical data (photographs, X-ray images, audio, patient records, videoconferences, etc.) from one site to another via the Internet, Intranets, PCs, satellites, or videoconferencing telephone equipment in order to improve access to health care." According to the Telemedicine Report to Congress (1997), "telemedicine can mean access to health care where little had been available before. In emergency cases, this access can mean the difference between life and death. In particular, in those cases where fast medical response time and specialty care are needed, telemedicine availability can be critical."

Telemedicine interactions are generally classified as either prerecorded (also called "store-and-forward") or real-time (also called "synchronous"). In the former, information is acquired and stored before being sent to an expert for interpretation at some later time. E-mail is a common method of store-and-forward interaction today. In contrast, in real-time interactions, there is minimal appreciable delay between the information's collection, transmission, and

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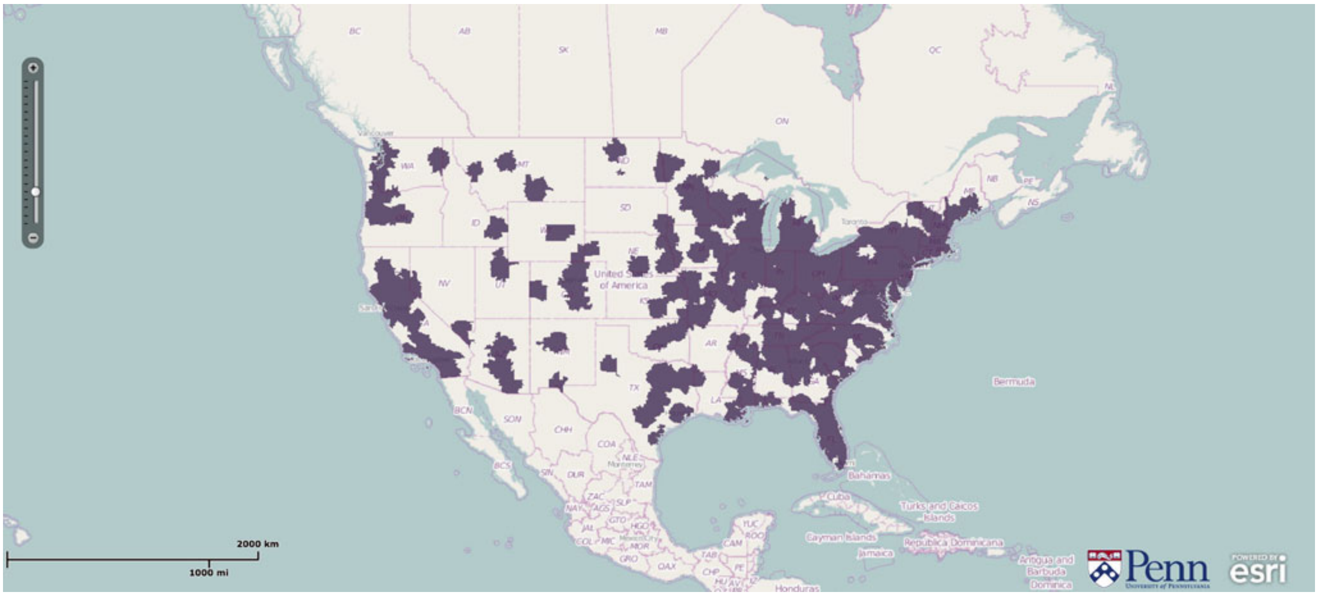

Fig. 23.1 US trauma system coverage. *Shading* denotes helicopter or ambulance transport within 1 h of a level I/II trauma center. Carr BG, Branas CC. TraumaMaps.org Trauma Center Maps. University of Pennsylvania Cartographic Modeling Laboratory. Copyright © 2006 Trustees of the University of Pennsylvania. Available from: www.traumamaps. org. Used with permission from the University of Pennsylvania

display. Interactive communication between individuals at the sites is therefore possible. Videoconferencing is a common method of real-time interaction.

The common thread for all telemedicine applications is that a client (e.g., patient or health-care worker) obtains advice or—as we will likely see in the future with haptics (tactile feedback technologies which recreate the sense of touch) and robotics—direct intervention from someone with more expertise, even when the parties are separated by space, time, or both.

History and Development

As human beings spread throughout every environment on the globe and even into space, the need for the technology to push health care to the patient has followed. Telemedicine has thus developed into many different entities that at their core deliver information over great distances thus improving access to medical care. Describing its broad scope, Reid defines telemedicine as "the use of advanced telecommunications technologies to exchange health information and provide health care services across geographic, time, social, and cultural barriers" [1]. The need to overcome these varied barriers has driven the growth of telemedicine into multiple outlets and practices.

Telemedicine can be classified by the type of interaction between the client and health care expert in contrast with the content of information being transmitted [2]. In "store and forward" telemedicine, there is an inherent delay in the interpretation of the data but access to advanced technologies aids the definitive care of the patient. Cardiology event monitors, diagnostic images, or expert e-mail consultation are examples of "store and forward" technologies. Real time interactions allow an immediate assessment of the patient, data, and situation to expedite appropriate care with the remote assistance of a subject matter expert. One such example are simple audio feeds broadcast over various networks that provide first responders the ability to interact with Emergency Medicine physicians and appropriately triage patients to specialty centers. Tertiary care hospitals use networked programs to link with rural or suburban areas over high-speed lines or private point-to-point connections for telecommunication amongst providers. The information transmitted can range from text and audio to more sophisticated interactions such as images, video, or robotic interfaces that may allow a combination of several interfaces.

The term "telepresence" describes the ability of health care providers to interact in real time with telecommunication equipment, allowing for immediate feedback and assistance. Adapted for trauma, telepresence allows experienced trauma surgeons or critical care providers to bridge the experience and access gap to trauma care that may exist in rural settings [3]. Telemedicine serves as an interface for inter-hospital trauma care between echelons of care, in the prehospital setting to guide the care of first responders, or as a mobile system deployed to disaster settings [3].

In its simplest form, telemedicine began as a sort of public health service in the middle ages, where bonfires in Europe were lit to signal the spread of bubonic plague. Outside of simple mail service, the technology slowly developed until the telegraphy was utilized in the 1800s by American Civil War surgeons to create casualty lists and request supplies. The telephone allowed further advances in the early twentieth century, ranging from simple communication to the transmission of heart sounds from an amplified stethoscope. A telepsychiatry program at the Nebraska Psychiatric Institute was developed by Dr. Cecil Wittson in the 1950s and expanded in the 1960s to encompass real-time consultation via closed-circuit television [4].

Early modern telemedicine is associated with another technological boon of the twentieth century—the National Aeronautics and Space Administration (NASA). NASA expanded on the telelinks that relayed biometric data collected from animals sent into space to develop the Integrated Medical and Behavioral Laboratories and Measurement Systems (IMBLMS) program in 1964. IMBLMS sought to move past simple monitoring to actual assistance of an astronaut in the delivery of self-aid or buddy-aid when a return from orbit was impractical [5]. This technology matured in a terrestrial form through a partnership between NASA, the Papago Indian Reservation, Indian Health Service, and the Department of Health, Education, and Welfare with Arizona's Space Technology Applied to Rural Papago Advanced Health Care (STARPAHC). The service was provided from 1972–1975, and delivered health care in the underserved Papago Reservation through a van staffed by paramedics who broadcast data such as X-ray images over a two-way microwave transmission to physicians at the Public Health Service Hospital [6]. Given limitations in technology and timeliness of the care that could be provided, nearly all of these efforts focused on routine care.

In 1978, Dr. R. Adams Cowley simulated a response to a crash of a DC-6 airplane wherein providers were able to transmit images of burn victims in real-time via satellite to a burn unit in San Antonio and medical centers throughout the Washington DC area [7]. The use of satellites for medical support in disaster management was first seen during the coordination of international rescue assets after the Mexico City earthquake of 1985 [8]. Satellite transmission has become the mainstay of large data transmission but its cost and large platform size often limits its wide scale application. The expanded use of devices with access to broadband global area networks (BGAN) now allow for a portable communication device to provide telemedicine in areas devoid of local networks. Cost can still be an issue, though BGAN systems have the upload and download speeds to perform video teleconferencing in contrast to cheaper very small aperture satellite systems. Used in multiple configurations, devices with BGAN connectivity have been used in remote settings such as rural Africa to provide real-time ultrasound interpretation [9]. The military has incorporated devices with BGAN connectivity to aid first responders in the triage and treatment of casualties [10]. In areas where the infrastructure exists, wireless cellular-based broadband has enabled a wide array of potential therapeutic interventions through the use of smartphones and laptops with applications to acquire, interpret, and transmit data. Modern trauma telemedicine and telepresence centers often use a combination of such systems to interact in the prehospital and inter-hospital settings [3].

Outcomes

The use of telemedicine has amassed impressive evidence supporting its use as a reliable, reproducible technology feasible across multiple platforms and venues of care. Central to its utility is the ability to improve access to health care, but a significant cost advantage lies in its ability to improve the triage of trauma patients. Rogers et al. [11] in 2001 described a tele-trauma program in rural Vermont in an observational study evaluating the impact of a real-time telemedicine consult with a trauma surgeon and a community hospital emergency department. In 41 consultations consisting mostly of motor vehicle collisions (49 %) and/or blunt trauma (95 %), 31 were transferred to the tertiary care center, of which three cases were considered lifesaving. Patient disposition was the predominant query, and 15 % of cases were kept at the referring facility. Eighty percentage of providers surveyed felt that telemedicine improved patient care.

Duchesne et al. conducted a comparative analysis of outcomes before and after the introduction of telemedicine in the management of trauma patients treated at seven rural emergency departments in Mississippi [12], demonstrating both improved rural evaluation and management. The hospitals utilized remote controlled video cameras to evaluate the management of traumatically injured patients over 5 years, comparing 351 historical controls directly transferred to the trauma center with 463 virtual consults. Of the virtual consults, only 51 patients were triaged to the trauma center despite telemedicine patients having a higher Injury Severity Score (18 vs. 10, $p < 0.001$), with no differences in patient age, sex, method of transportation, or mortality. An impressive difference in hospital cost was found between the groups (USD 1,126,683 vs. 7,632,624, $p < 0.001$) suggesting telemedicine significantly improved evaluation and management of rural trauma patients at reduced costs without significant changes in mortality.

In a retrospective analysis of one of the more robust telemedicine centers in the USA, Latifi et al. described their early experience of a telemedicine system involving five rural hospitals and a Level I trauma center in southern Arizona [13]. In a retrospective analysis of 59 tele-consults involving a mix of general surgery (41 %) and trauma patients (59 %), 29 % of patients were held at their referring hospital for ongoing care while six tele-consults led to potentially lifesaving therapy. Reducing transfers saved an average of USD 19,698 per air transport or USD 2,055 per ground transport, again suggesting a telepresence can effectively improve trauma outcomes while reducing costs.

In a study of telemedicine for 70 burn patients, Saffle et al. described a 55.7 % reduction in emergent transfers to a burn center compared with a historical cohort [14]. Ten patients were effectively discharged from their referral center's emergency department. In addition to the decreased transfers, this strategy allowed for more effective utilization of the increasingly limited resource of the modern burn center. Interestingly, estimates of burn sizes by burn center physicians correlated between telemedicine and direct inspection estimates, though both differed significantly from the estimates of the referring physician, suggesting not only a reduction in the overtriage or undertriage inherent in initial burn assessment but also the diagnostic integrity of the telemedicine system on a clinical variable likely to have significant impacts on care and patient outcome. Notably, the telemedicine interaction was also viewed favorable by both providers and patients.

In a Canadian evaluation using videoconferencing and the transfer of a real-time ultrasound information, Dyer et al. were able to observe and direct 20 acute, focused assessment with sonography for trauma (FAST) exams, identifying five cases of hemoperitoneum and two pneumothoraces, while also being able to provide feedback for the sonographer [15]. The ability of telepresence to fill the experience gap present in trauma care was again demonstrated when, using a videolarygoscope modified with a Wi-Fi module broadcasting over a telemedicine network, a physician specializing in airway management was able to assist a healthcare provider performing tracheal intubation in a remote hospital [16].

Developing a Telemedicine System

Multiple factors will inevitably surface to impede the easy implementation of a telemedicine program. Though an individual location's factors will vary widely, at a minimum, an institution considering adopting such an innovation should:

1. Develop a comprehensive business plan, to include information technology and administrative support at all hours if necessary.
2. Assess the need for administrative or structural changes required for its incorporation in the delivery of care.
3. Conduct a feasibility assessment.
4. Build infrastructure when necessary.
5. Encourage and provide funding for telemedicine development and research, often through the designation of promising and respected local champions.
6. Develop a plan for implementation (once clinical effectiveness and cost-effectiveness have been demonstrated).
7. Gain "buy-in" from all staff (physicians, nursing, information technology, administration, patient advocacy).
8. Create training, practice guidelines, credentialing, and continuing quality improvement mechanisms.
9. Address overarching and local ethical and medicolegal concerns.
10. Ensure the security of patient data under existing privacy regulations.
11. Integrate clinical staff (user) concerns into any engineering or technical changes.
12. Account for linguistic and literacy differences.
13. Be sensitive to particular technical and organizational factors, allowing for continuous reporting, disclosure, and full transparency.

Significant learning curves for the use of technology must be anticipated. Partnering with an existing telemedicine program may help to gain acceptance of new ideas through the careful application of lessons learned. Naturally, as with any new technology applied to a field with proud traditions (such as trauma care), reluctance to adopt new practices will need to be expected, appreciated, and managed through the careful accumulation of data and the politic presentation of new ideas.

The Future

"Moore's Law," the observation that computer processing speeds have doubled roughly every 2 years and will likely continue to do so for the foreseeable future, will further enable innovation in telemedicine to bridge the austerity-trauma divide. As Internet and broadband communications improvements accumulate, the fidelity and reproducibility of telemedicine systems will lead to faster collaborations between clinicians, more efficient use of resources (including improved diversion amongst hospitals based on availability of assets), cost savings throughout the spectrum of care, improved access to the electronic health record, and better patient outcomes, engagement, and even follow up after discharge. Though there are several emerging technologies and ideas worth exploring, nearly all of their potential in contributing to augmented trauma care can be traced to improvements in computing power, speed, and integration.

While in some aspects still the stuff of science fiction, telemedicine in its most developed state will compress or even negate the impositions and limitations of distance, rendering the recognized flow of "Point of Injury—En Route Care—Emergency Department—Operating Room—Intensive Care Unit" distinctions obsolete. Integrated wearable or even implantable sensors [17] will instantly detect trauma in a particular patient, inform the echelons of care to initiate response and evacuation, and even, as in the case of certain designs of exoskeletons, either prevent certain traumas (as in the sense of a body armor function [18] or a haptic vibrating "early warning" system [19]) or initiate some form of self-aid (as in an exoskeleton with incorporated extremity tourniquets). Effective integrated sensors of this type are already being investigated by various militaries, and in the case of a mass casualty involving multiple injured soldiers, will even assist in triage, informing first responders even before their arrival on scene of patient criticality and triage priority.

Once medical professionals arrive, several mobile diagnostic devices, miniaturized ultrasounds, and various other "apps" will augment their capabilities to diagnose and treat field trauma, including "Tricorder" devices solicited through such calls as the Nokia Sensing XCHALLENGE competition. Wearable integrated sensing and communications technologies such as the ULTRA-Vis [20] or the Google Glass and others will allow first responders and remote advanced practitioners to have instant decision support from trauma experts located anywhere in the world (or beyond), while at the hospital, such devices will contribute to more seamless integration of data or checklists in a real time, hands free "heads up display" that a clinician will be able to utilize simultaneously, even while scrubbed into a procedure [21].

Remote diagnostics and therapeutics will be made even more accessible through the improvement in existing haptics technologies that transmit palpatory stimuli from the patient to a remote practitioner. While exoskeleton devices that provide tactile or auditory "early warning" are already in various stages of use in the military and can aid further in the prevention of trauma, further advances in such feedback modalities will continue to improve tactile sensation in remote robotic surgery. Though some skeptics may argue robotic surgery yields no better outcome than traditional surgery [22], it is difficult to argue that remote robotic surgery is any way inferior to receiving no treatment in those cases that no competent surgeon is on site to deliver care personally.

Although beyond the scope of this chapter, innovations in transportation and robotics deserve brief mention. Tremendous strides in communication and interconnectivity have drastically improved ground and aerial medical evacuation through better patient tracking, medical information sharing, and the integration of medical devices in various "flying ICU" configurations. Advanced device integration, already revolutionizing intensive care and patient safety [23], can even allow remote monitoring of patients and adjustment of ventilators and medication pumps when medical attendants cannot be at the patient's bedside, as in fixed-wing takeoff and landing [24]. Nanotechnology applied to robotic surgery and embolic therapy is gaining acceptance [25], while the self-driven car of today [26] will become the self-driven ambulance and self-flying helicopter of tomorrow. Robotic extraction systems [27] will expand the reach (and safety) of first responders, even obviating the need to put a person at risk to rescue a patient, just as unmanned underwater vehicles and robotic explosive ordnance devices have done respectively for human divers and bomb technicians.

Undergirding all these advances will be a powerful and ubiquitous network of data storage, decision support, additive manufacturing ("3D Printing"), and Artificial Intelligence aids that will be able to assist the clinician in determining courses of treatment based on best available evidence [28]. The additive manufacturing of today that fashions surgical tools that more readily fit the surgeon's hand or construct an implantable cranioplasty, will become the bioprinters [29] of tomorrow capable of "growing" tissues, and eventually, organs, from host cells. Remote computing will likewise allow for the completion of many tasks virtually, from interpreting a radiologic study remotely on a mobile device before patient arrival to ordering a study or writing that note one forgot to complete through a secure telework system at home.

But such network advances will not only help the clinician in addressing trauma, perhaps the greatest influence of technology will be in the realms of social media, crowdsourcing, the influencing of opinion, and the empowerment of the consumer toward healthy behaviors. Indeed, the traumatologist of the future may not only be able to care for victims of trauma more efficiently and effectively, but will also play a role in steering them from harm, thereby preventing some from ever becoming patients in the first place.

Key Points

1. Telemedicine is the use of electronic signals to transfer medical data from one site to another via the Internet, Intranets, PCs, satellites, or videoconferencing telephone equipment in order to improve access to health care.
2. Telepresence describes the ability of health care providers to interact in real time with telecommunication equipment, allowing for immediate feedback and assistance.
3. *Telemedicine and telepresence offer opportunities for remote triage and perhaps even remote patient care potentially reducing overtriage and undertriage and ultimately improving patient care.*

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Imaging in the Stable Trauma Patient

24

Bradley S. Moffat and Neil G. Parry

Abbreviations

ABC	Airway, breathing, circulation
ATLS	Advanced trauma life support
C-spine	Cervical spine
E-FAST	Extended focused assessment by sonography in trauma
EMS	Emergency medical services
FAST	Focused assessment by sonography in trauma

Introduction

The hemodynamically stable trauma patient affords the trauma practitioner valuable time to consider a variety of treatment adjuncts. Such patients are excellent candidates for a wide arsenal of imaging modalities. However, thoughtful planning of the types and sequence of imaging tests can minimize the time spent in uncontrolled environments and facilitate transition to definitive care.

When considering appropriate imaging studies for any trauma patient, the most important question to ask is: "*Is this patient hemodynamically stable*?" Any patient showing signs of significant tachycardia, hypotension, or any other ABC (airway, breathing, circulation) concern should not leave the trauma bay for imaging purposes and should never be sent to the CT scanner. Being in the CT suite or in transit can be very challenging if the patient deteriorates or needs ongoing aggressive resuscitation.

In this chapter, we will review the imaging modalities available for stable trauma patients. Further, we will discuss some strategies for planning a smooth and efficient transition from the trauma bay, to the imaging suite, and finally to definitive care.

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Imaging Modalities

Plain X-Ray

Plain film x-rays confer a major advantage over many other modalities in that they are portable and can easily be performed in the trauma bay. Many trauma bays are equipped with ceiling mounted x-ray systems which eliminate the need for bulky portable equipment. Plain film x-rays are an important adjunct to the ATLS (advanced trauma life support) primary survey and include lateral cervical spine (C-spine), chest, and pelvic studies [1]. They are also relatively inexpensive compared to other imaging modalities.

The lateral C-spine film has been largely replaced by CT [2]. Even in centers where CT is not available, lateral C-spine films alone are not sufficient to clear C-spine precautions and may miss up to 55 % of injuries [3]. In select alert patients, C-spine precautions may be cleared clinically using a tool such as the Canadian C-Spine Rules [4] (Fig. 24.1). Most patients with a significant mechanism of injury will go on to have a CT C-spine and hence the plain film is not necessary. The cervical collar must therefore remain on until the C-spine has been cleared.

The chest x-ray is a critical imaging study for all trauma patients. Certain key findings mandate treatment prior to leaving the trauma bay. Patients with a significant hemo- or pneumothorax should have a chest tube inserted prior to leaving the trauma bay as these injuries can worsen rapidly (Fig. 24.2).

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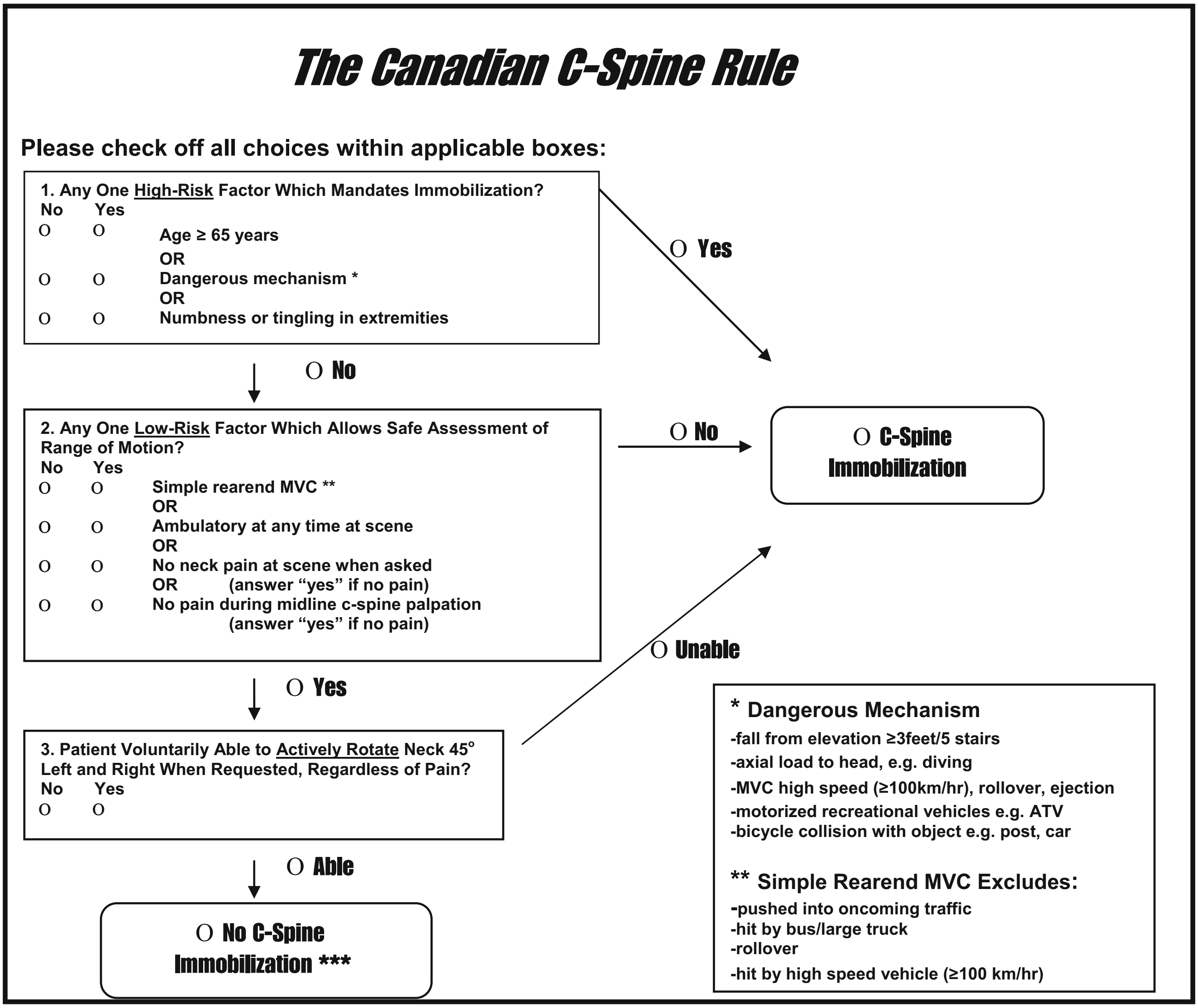

Fig. 24.1 Canadian C-spine rule. Abbreviations: Glasgow Coma Scale (GCS), Motor Vehicle Collision (MVC), Emergency Department (ED). (Adapted from Vaillancourt et al. Evaluation of the safety of c-spine clearance by paramedics: design and methodology. BMC Emerg Med. 2011 Feb 1;11:1. doi: 10.1186/1471-227X-11-1. With permission from BioMed Central)

A widened mediastinum would also raise the possibility of blunt aortic injury. With intubated patients, the chest film is also a helpful adjunct to confirm adequate endotracheal tube position prior to transport. As mentioned in Chap. 13, while useful to locate the tip of the endotracheal tube and rule out a right main stem intubation, it is important to remember that a chest x-ray cannot differentiate between an esophageal or tracheal intubation and other clinical signs and confirmatory tests must be employed. Ultrasound can also play a key role in diagnosing and ruling out hemo- or pneumothorax. Additionally, ultrasound can reliably detect esophageal intubation and main stem intubation at the bedside, in real time.

The pelvic film is also often being replaced by CT. In the clinically stable pelvis, the pelvic film is sometimes omitted if the patient is hemodynamically stable and going for CT which will include the pelvis. However, if the patient is not going for CT imaging or if there is any suggestion of hemodynamic instability, the pelvic film should be performed. In the clinically unstable pelvis, a binder should be applied and a pelvic film should be obtained prior to leaving the trauma bay.

Extremity films may be considered as adjuncts to the ATLS secondary survey as such films can often guide the urgency of orthopedic intervention [1]. With limb-threatening orthopedic injuries, pre- and postreduction films may be necessary prior to leaving the trauma bay. In the hemodynamically stable patient, extremity films may also be helpful in guiding the astute trauma practitioner to add extremity CT scans for injuries in which the orthopedics team may require them (such as injuries involving major joints). This can help

Fig. 24.2 Chest x-ray—large right pneumothorax. (Reprinted with kind permission from Springer Science+Business Media: Pediatric Surgery International, Complete bronchial rupture in a child; report of a case. 21(8); 2005, Okumus M, Fig. 1)

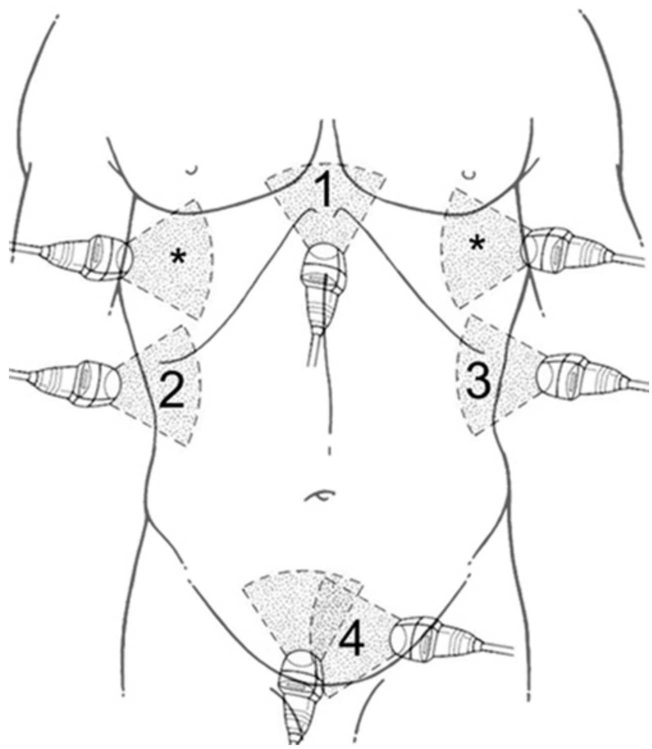

Fig. 24.3 Ultrasound probe positioning for FAST. (Reprinted with kind permission from Sprin ger Science+Business Media: Notfall and Rettungsmedizin , Aktueller Stellenwert der konventionellen Radiographie und Sonographie in der frühen Versorgung traumatisierter Patienten, 13(6); 2010, Geyer, L.L, Fig. 3)

eliminate the need for additional trips to the radiology suite after the patient reaches definitive care. However, timely transit to CT should not be delayed in favor of getting extremity films.

Focused Assessment with Sonography for Trauma (FAST)

As outlined in the preceding chapters, the FAST exam has become a critical adjunct to the ATLS primary survey [1, 5–7]. While the primary function of the FAST exam is to exclude hemoperitoneum and hemopericardium in the unstable patient, it remains a mandatory adjunct in the stable patient as well. Stable patients with a positive abdominal FAST should still proceed to CT scan. However, if a patient with a positive FAST becomes unstable after leaving the trauma bay, they can be quickly rerouted to the operating room for definitive management (Fig. 24.3). On the other hand, stable patients with a positive pericardial FAST should most likely proceed directly to the operating room.

Many trauma providers are becoming facile with the extended FAST (E-FAST) exam. In addition to the four abdominal views, the E-FAST includes bilateral assessment for pneumothorax and hemothorax. Like the standard FAST, the primary utility of the E-FAST views is to guide chest intervention in the unstable trauma patient. The E-FAST views can still be a helpful tool in the stable trauma patient where the clinical exam is equivocal and the chest x-ray is either delayed or equivocal. An important consideration to the use of E-FAST in the stable patient is its high specificity; that is, the E-FAST may detect small volumes of air or fluid which are not apparent on chest x-ray [8]. Such occult injuries are often managed conservatively, and hence chest tube placement may be delayed until CT imaging is obtained or deferred entirely.

CT Scan

CT is the mainstay imaging modality for the stable trauma patient and careful consideration should be given to each body area which may require CT imaging. Once the primary and secondary surveys are complete, the patient may be prepared to travel to the CT suite. Mechanism of injury and physical exam findings generally dictate which areas should be further imaged with CT. However, certain injuries warrant special mention.

Much like with C-spine, the Canadian CT Head Rule helps determine who requires a CT head [9] (Table 24.1). CT angiogram of the chest has become the gold standard to diagnose blunt thoracic aortic injury. Such a diagnosis should be suspected in patients that suffer sudden acceleration-deceleration-type injuries (e.g., head-on motor vehicle collision, fall from height). Most stable trauma patients with abdominal pain and/or a positive FAST should undergo CT imaging of abdomen and pelvis (Fig. 24.4). CT scans of the

Table 24.1 Canadian CT Head Rule

CT Head is only required for patients with minor head injuries[a] with any one of the following:
High risk (*for neurological intervention*)
• GCS score <15 at 2 h after injury
• Suspected open or depressed skull fracture
• Any sign of basal skull fracture (hemotympanum, "raccoon" eyes, cerebrospinal fluid otorrhea/rhinorrhea, Battle sign)
• Vomiting ≥two episodes
• Age ≥65 years
Medium risk (*for brain injury on CT*)
• Amnesia before impact >30 min
• Dangerous mechanism (pedestrian struck by motor vehicle, occupant ejected from motor vehicle, fall from height >3 feet or five stairs)

Reprinted from Stiell et al. The Canadian CT Head Rule for patients with minor head injury. *Lancet*. 2001; 357:1391–1396 with permission from Elsevier

[a]Minor head injury is defined as witnessed loss of consciousness, definite amnesia, or witnessed disorientation in a patients with a GCS score of 13–15

Fig. 24.4 CT scan of the abdomen—blunt splenic injury with blood tracking around the spleen and liver. (Reprinted with kind permission from Springer Science+Business Media: European Journal of Trauma and Emergency Surgery, Correlation of operative and pathological injury grade with computed tomographic grade in the failed nonoperative management of blunt splenic trauma, 38, 2012, Carr JA, Fig. 5)

thorax, abdomen, and pelvis require good arterial phase intravenous contrast. Delayed films for venous phase or to evaluate urinary tract injuries may also be helpful depending on injuries found.

Many trauma patients require a "pan-scan" which includes the head, C-spine, chest, abdomen, and pelvis. CT pan-scan detects up to an additional 40 % of injuries, 20 % of which are clinically significant, when compared to selective imaging [10, 11]. Furthermore, there is a distinct survival benefit to patients who undergo pan-scan [12]. This method also allows one to radiographically examine the entire spine. CT pan-scan should be strongly considered for any stable blunt trauma patient with significant mechanism of injury and/or decreased level of consciousness.

Stable patients sustaining penetrating trauma may be candidates for more selective imaging. Consideration must be given to the possible path of the missile and all body cavities at risk should be included if CT imaging is sought [13]. Penetrating wounds to the neck are triaged based on clinical exam into bedside exploration, contrast CT, or operative exploration [14]. There are several approaches to penetrating thoracoabdominal trauma. Gunshot or stab wounds to the chest are often imaged with CT. Any injury to the thoracoabdominal junction needs to be evaluated for diaphragmatic injury. While CT technology is improving, the radiographic detection rate is still not ideal [15] and laparoscopic or thoracoscopic evaluation of the diaphragm is usually warranted. Low velocity (eg. stab wounds) penetrating injuries to the anterior abdomen can often be managed by serial physical exams as bowel injuries can be missed on early CT scanning. Penetrating injuries to the flank should undergo triple contrast CT scan (IV, oral, and rectal contrast) as serial exams may miss retroperitoneal injury [13]. CT imaging may be warranted in blunt or penetrating extremity trauma based on clinical exam and contrast studies are often helpful to exclude major peripheral vascular injury.

The trauma practitioner is tasked with weighing the benefits of CT imaging against the potential risks of radiation exposure. The average radiation exposure for a single trauma pan-scan is about 31 millisieverts (a standard CT head is about 1.7 millisieverts) [16]. The use of CT in the pediatric population warrants extra caution as it has been associated with increased cancer risk, especially in young children [17]. While the CT pan-scan provides invaluable information, consideration should always be given to cumulative radiation exposure, especially in the pediatric patient. Imaging in the pregnant patient also requires specific considerations which are discussed in detail in Chap. 19.

Other Modalities

Several newer modalities are becoming available to trauma providers as imaging technology advances. Whole-body plain film imaging is a technology which was derived for screening diamond mine workers against smuggling. It generates a whole-body supine x-ray in a short time span. The technology is proving to be particularly helpful for diagnosing multiple extremity fractures which may otherwise go unnoticed in the severely injured patient.

Another emerging technology is the portable CT scanner. Some trauma bays are already equipped with these devices which allow rapid scanning without the need to leave the trauma bay. While the image quality is below most standard CT scanners, the rapid accessibility can be very helpful especially when a limited scan can change management in the trauma bay (e.g., assessing an evolving brain injury).

Critical Thinking

There are a variety of important considerations when planning a trip to the imaging suite with a stable trauma patient (Fig. 24.5). Careful planning and clear communication are key to ensuring a smooth process.

A chest x-ray and a FAST exam should be performed on all trauma patients before they leave the trauma bay. Calling for the x-ray technician early will avoid delays in waiting for plain films to be obtained. Likewise, having an ultrasound machine and a certified FAST user close at hand is a must.

If an inter-facility transfer is anticipated, advanced imaging (such as CT) should be deferred or kept to a minimum. The appropriate land or air emergency medical service (EMS) personnel should be contacted as soon as a transport decision is made such that delays in waiting for their arrival are minimal. Bear in mind that CT scans performed at your hospital may not be transferable to the receiving facility and often these scans end up being repeated when the patient arrives [18]. Hence, scanning prior to transfer may expose the patient to additional radiation and/or delays in transfer. Only consider scans which may alter your management prior to or during transfer.

Upon completion of the primary survey in a stable patient, the trauma practitioner should start considering which CT scans may be required. As soon as this decision is made, the trauma team leader should immediately be in communication

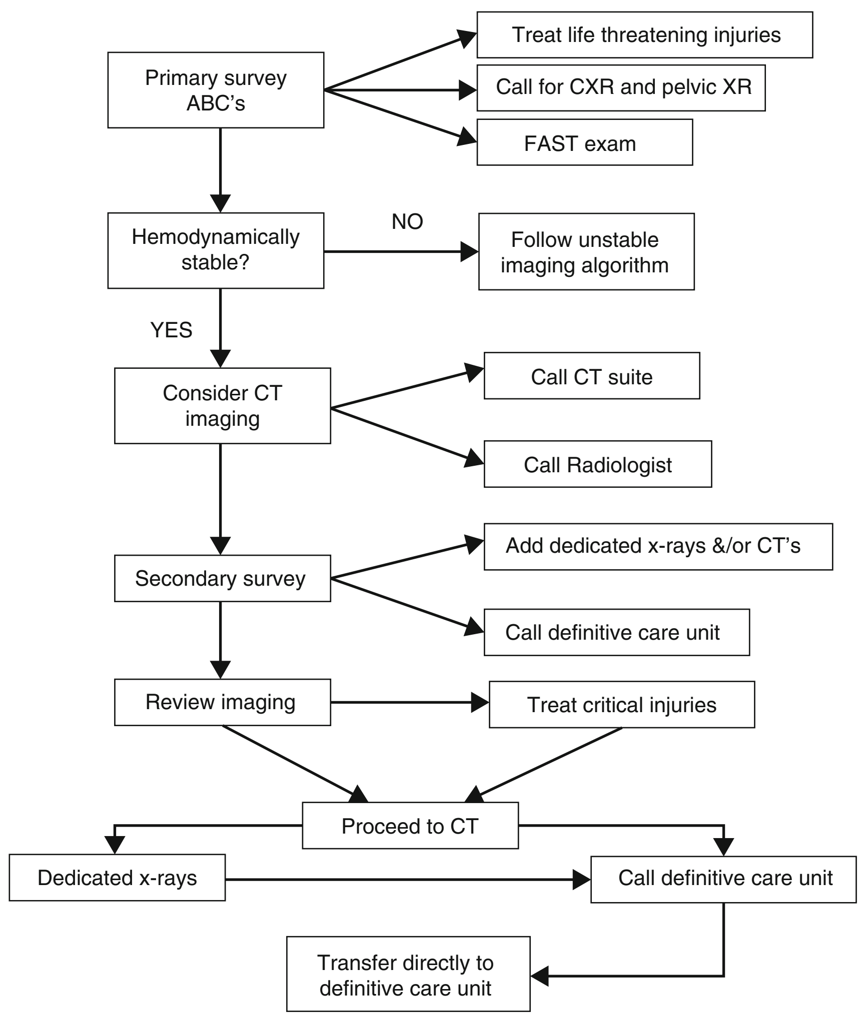

Fig. 24.5 Flow sheet for imaging in the stable trauma patient

with the CT suite to notify them and find out when they can accept the patient.

Once CT has been notified, the FAST exam and the plain film x-rays should be in progress or already be available. These studies should be carefully examined for any injuries which may need to be treated prior to leaving the trauma bay (such as a pneumothorax). The secondary survey should also be completed at this point.

It is important to anticipate additional CT scans that may be needed based on specific injury patterns. For example, if there is significant facial trauma on clinical exam, adding a dedicated CT face to the initial trauma scans will save an additional trip to the scanner later. Another common example is fractures involving major joints which often require CT imaging prior to operative intervention. Aggressive screening for blunt cerebrovascular injury with CT angiogram of the neck should also be considered for patients with cervical spine fractures, major facial fractures, skull base fractures, or neurologic injuries not explained by CT head [19–21]. Clear and early communication with consulting services can also help plan such adjunctive imaging.

Before leaving for the scanner, it is important to ensure you have the appropriate transfer equipment. Be sure to bring standard resuscitation equipment as well as any analgesic and sedating medications you may need. At a minimum, a physician (ideally the trauma team leader) and a nurse should accompany the patient at all times until they reach definitive care. If the patient is intubated, a respiratory therapist should also stay with the patient at all times.

Another important consideration before leaving the trauma bay for the CT suite is where the patient will go after their scans. If the patient is being admitted, the trauma team leader should decide what level of care is required as soon as possible. It is critical to give the floor, observation unit, or intensive care unit as much notice as possible to ensure a bed is available and staffed. Frequent communication with those in charge of these beds is important. The goal should be to transfer the patient from the trauma bay, to the scanner, then directly to definitive care. This avoids unnecessary time spent in transit and in the emergency department and further minimizes the time spent in uncontrolled environments. After the bed request is made, it is helpful to touch base when leaving the trauma bay to the CT suite and again when leaving the CT suite to ensure the bed is prepared and the definitive care team is ready to transfer care as soon as the patient arrives.

When caring for the stable trauma patient, astute planning and a smooth transfer from the trauma bay, through the imaging department, and finally to definitive care will improve patient care and maximize efficiency.

Key Points

- Always ask: "*Is this patient stable*?" If not, do not transfer them to the CT scanner.
- Ensure all trauma patients have a chest x-ray and FAST exam done prior to leaving for the scanner and act on any injuries which could progress.
- CT scan with a low threshold for pan-scan is the modality of choice for most stable, blunt trauma patients.
- Carefully consider which scans are needed urgently and anticipate additional scans which may be required by consulting services.
- Communicate early and clearly with the CT suite and the definitive care unit to ensure a smooth transit for the patient.

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Part VI

Tactical Emergency and Disaster Medicine

Disaster Medicine

25

Michelangelo Bortolin and Gregory R. Ciottone

Abbreviations

CBRN	Chemical, biologic, radiological, and nuclear
EMS	Emergency Medical Services
EOP	Emergency operations plan
HIV	Human immunodeficiency virus
HVA	Hazard and vulnerabilities assessments
IAP	Incident action plan
IC	Incident commander
ICS	Incident Command System
PTS	Posttraumatic stress
SARS	Severe acute respiratory syndrome
SOP	Standard operating procedures

Introduction

Devastating events such as natural disasters like the typhoon in the Philippines (2013) and the earthquake in Haiti (2010), intentional events like the terrorist attack in New York (2001), and the sarin attack in Tokyo's subways (1995) demonstrate that disasters are both unpredictable and ubiquitous.

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Disaster is defined as any event that causes "a serious disruption of the functioning of a community or a society involving widespread human, material, economic or environmental losses and impacts, which exceeds the ability of the affected community or society to cope using its own resources" [1].

Considering that any number of different events could hit a population at any time, there is no place on earth completely immune to disasters. Therefore, disaster medicine was created as a broad specialty grounded in emergency medicine, but utilizing the skill sets of other surgical and medical specialties, and only able to become operational in combination with the systems supported by disaster management. For example, during an earthquake, several specialties are involved in the response and immediate care of the victims: emergency physicians, surgeons, anesthesiologists, and orthopedics; however, other subspecialties are also required in the ongoing care of victims. These include nephrologists to treat acute renal failure related to crush syndrome, both during and following the event, and psychosocial and rehabilitation specialties for continued care. These medical and surgical specialists are only able to perform their roles under the umbrella of disaster management. Without being enabled by the logistics and operations capabilities seen in a large-scale disaster response, these specialists would not be functional.

Natural or Man-Made Disaster

Disasters are typically categorized as natural or man-made events. Natural disasters, such as floods, tsunamis, and earthquakes, typically have a more extensive impact on population centers, causing more disruption. Hurricane Katrina in 2005 ravaged Louisiana, Mississippi, Alabama, and Florida causing death, numerous casualties, mass evacuations, and disruptions. Natural disasters also include epidemics. In the past, cholera, bubonic plague, and other diseases affected entire continents causing millions of casualties. Today, non-intentional outbreaks and pandemics such as influenza

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outbreaks and human immunodeficiency virus (HIV) are just two examples of natural disasters that for several reasons can spread quickly, ravaging entire communities. The Spanish flu in the early 1900s caused more than 50 million deaths, and severe acute respiratory syndrome, (SARS) that arose from China in 2003, resulted in thousands of death in that part of the world and concern for a global pandemic. Another virus that afflicts and kills millions of people, particularly in the poor areas of Africa and developing countries, is HIV. It is estimated that from the 1980s, HIV has caused more that 30 million deaths around the world. An estimated 97 % of natural disaster-related deaths occur in developing countries (World Bank, 2000–2001) [2].

Man-made disaster is defined as any event that is caused by the activity of human beings. Explosions, building collapse, civil wars, and nuclear accidents are some examples. The collapse of the Hyatt Regency Hotel in Kansas City in 1981 is one such example. Investigations found that the cause of the collapse was due to an engineering problem. There were more than 100 deaths and more than 200 casualties from that disaster. The transportation industry is commonly involved in incidents that cause large numbers of injured and dead. In 1998 in Eschede, Germany, a high-speed train derailed causing 101 fatalities. Other industrial sectors, such as the chemical industry, have also been involved in man-made catastrophes. In December 1984 in Bhopal, India, more than half a million people were exposed to methyl isocyanate. In the immediate phase after the leak, almost 10,000 people died. The Indian Government has calculated that this event has caused over the years almost 600,000 casualties due to lingering effects of the chemical exposures [3, 4].

The 9/11 terrorist attack in New York and the Oklahoma City bombing (1995) are also man-made disasters. It is important to recognize and underline that disasters also result from war, the conduct of repressive regimes, the use of sanctions, as well as economic and social policies, particularly in developing countries [5]. The Syrian Civil War arose in the 2011 and has caused more than 120,000 deaths and more than 2.3 million refugees since 2013 [6].

The Disaster's Cycle

Disasters and the response to them follow a pattern called the disaster cycle, which is defined in four phases: mitigation and prevention, preparedness and planning, response and recovery.

Mitigation and prevention involve measures designed either to prevent hazards from occurring or to lessen the effects of the disasters [7]. These measures involve multiple different agencies and commissions, for example, policymakers introducing regulations regarding the storage, transportation, and disposal of chemical substances. Another example of mitigation is to empower a public health system to monitor and conduct surveillance for infection diseases and at the same time introduce rules regarding health screening at the borders. The importance of the mitigation phase is to avoid disaster or to reduce the impact on the population. It is clear if we compare the 2010 earthquake in Haiti, with a magnitude of 7.0, and similar earthquakes in Japan where despite the same magnitude the number of dead and injured were more limited, that we see the effect of a disaster is often dependent on the underlying condition of the area affected. For decades, Japan has introduced strict building codes that follow seismic regulations. Nevertheless, it is not possible to fully mitigate against all disaster events. For instance, the 2011 earthquake in the Pacific Ocean produced a tsunami that hit the east coast of Japan and caused severe damage, in particular a failure of the nuclear plant in Fukushima, with release of radiation that affected the local community.

The preparedness and planning phase includes all activities conducted on an ongoing basis, in advance of any potential incident. Preparedness involves an integrated combination of assessment; planning; procedures and protocols; training and exercises; personnel qualifications, licensure, and certification; equipment certification; and evaluation and revision [8]. The first step of preparedness is defining what events are more likely to hit a community. The Hazard and Vulnerabilities Assessment (HVA) is a way to objectively risk-stratify those hazards that are more likely to strike a given community. The HVA takes into account different events: natural, man-made, and CBRN (chemical, biologic, radiological, and nuclear). The output from an HVA prioritizes the risks to which a population is most susceptible and should therefore be prepared for. After the HVA, it is possible to then establish standard operating procedures (SOP) and the emergency operations plan (EOP) for the community or hospital. It is a good rule that the EOP adopts an all-hazards approach to preparedness, with annexes and appendices specific for every type of probable event [9]. An important part of the preparedness phase is training. In particular, every healthcare professional must be trained when to activate a disaster response and their own specific roles and responsibilities within the framework of the response. The typical drills commonly used are tabletop and full-scale exercises. They are important also to identify shortfalls, bottlenecks, and gaps in the EOP. The staff should take part in the training, and the EOP should be tested, reviewed, and updated at least once per year.

Response is the phase in which agencies and sections with responsibility to deploy to disasters activate their emergency response plan as a result of specific threats or situations and can incorporate local, regional, and federal response agencies [10]. The response is conducted through the intervention of several agencies and must be flexible and adaptable for any type of event. It is important to immediately establish a response framework with a unified command structure that establishes a chain of command, control, and coordinate the resources, in terms of staff, stuff, and structure. The Incident Command System (ICS) provides a structure to enable agencies with different legal, jurisdictional, and functional responsibilities to coordinate, plan, and interact effectively on scene [11]. The medical response is provided at the scene by the emergency medical services (EMS), with triage, treatment, and transport to the hospitals. EMS plays a crucial role in the immediate phase of the response to disaster. The response must be quick and effective on the scene as well as in the determination of hospital destinations for every patient, to guarantee an appropriate standard of care and to avoid bottlenecks and congestion at hospitals. Rarely, EMS is able to triage, treat, and transport every single patient from the scene. Often some casualties reach the closest hospital on their own, giving rise to disruption in the chain of triage and to the hospital. The ability of a healthcare system to suddenly expand its capacity beyond normal services to meet the increased demand for qualified medical staff and services during a large-scale event is defined as "surge capacity" [12]. The surge capacity depends on the features of the healthcare system, but also by an effective EOP and training of the staff.

The post-impact period revolves around disaster recovery in which the goal is to eliminate impairment caused by a disaster and rebuild communities and infrastructures [13]. Also this phase involves several agencies and may be long lasting, ranging from weeks to years. People affected by a tremendous disaster must face a long recovery phase. Survivors from the September 11, 2001, terrorist attacks on the Twin Towers not only had immediate treatment in the field and in the hospitals that day, but their treatment has continued for years. The majority of people exposed to disasters do well; however, some individuals develop psychiatric disorders, distress, or risky behaviors such as an increase in alcohol or tobacco use [14]. The Department of Health and Human Services spent months and years following the 9/11 attacks and has gone on to provide health care, both physical and mental, to those who were, and continue to be, affected and in need [15]. The recovery phase often also involves rescue workers as their exposure to the traumatic event has a severe impact on their mental health. Studies confirm that rescue workers are prone to have diseases or documented behavioral health disturbances following events. For example, several articles describe how the acute and prolonged exposures were both associated with a large burden of asthma and posttraumatic stress (PTS) symptoms years after the 9/11 attack.

Incident Command System

During an incident, the response must be effective and efficient. To achieve this, and thereby ensure that the best care possible is rendered to victims, it is fundamental to have a well-prepared and organized system.

The Incident Command System (ICS) is a standardized, on-scene, all-hazards incident management concept and allows its users to adopt an integrated organizational structure to match the complexities and demands of single or multiple incidents without being hindered by jurisdictional boundaries [16].

The ICS was developed in the 1970s in California to manage, command, and control fire brigades during their operations to extinguish wild fires. Shortly after that, it was adopted by EMS and other agencies, as well as endorsed by the U.S. Department Homeland Security as a fundamental element of incident management.

The ICS is used for all events and is modified depending on the size of the incident. Its goal is to manage and to resolve the incident with an efficient use of resources while protecting all persons involved. The ICS is a modular and flexible organizational system that can be standardized for multiple uses. The ICS is modified according to the size and complexity of the incident, specifics of the hazard, environment effected by the incident, the incident planning process and incident objectives (ICS expansion and contraction) [17].

The ICS establishes an incident commander (IC), who is in charge of all the activities regarding the incident, a chain of command, and unified command between the agencies. The priorities of the IC are three: the safety of the casualties and the rescue team, incident stabilization, and property preservation. Every incident must have an incident action plan (IAP) that establishes incident goals, operational period objectives, set activities, and the response strategy defined by the IC during response planning [18].

The IC manages and carries out his responsibilities with three features of command that are important for every role within the framework of the ICS: the chain of command, the unity of command, and the span of control. The chain of command is a key part of the ICS and is defined as a structure with a clear line of authority. The unity of command infers that every responder knows without question who his/her supervisor is. Span of control describes the typically 6–7 people a supervisor directly leads.

During a disaster, it is extremely important to establish a unified command, because it enables all responsible agencies to manage and coordinate an incident together by establishing a common approach and a single IAP. It permits the integration of staffing and shared facilities, with everyone having the same objectives and not replicating efforts [19].

The IAP describes activities, responsibilities, and the communication procedures. This system is fundamental to avoid confusion and lack of communications. Adequate and redundant communication systems are very important during the response to disaster. It is essential that the ICS use common terminology and integrated communications among agencies and establish precise ways of communications. The communication systems should be: interoperable between agencies; reliable to function in the context of any kind of emergency; portable, built on standardized radio technologies, protocols, and frequencies; scalable as the needs of the incident dictate; resilient to perform despite damaged or lost infrastructure; and redundant to enable the use of alternate communications methods when primary systems go out [20].

The ICS is supported by a command staff that includes a safety manager, a liaison officer, and a public information officer. It is organized into four sections, the general staff, which supports the ICS: operation, planning, logistics, and finance/administration.

The operation section is in charge of managing all the tactical operations on the scene; tactical operations include fire brigades, EMS, and every agency required for the incident. The planning section is responsible to draft the IAP; to get, receive, elaborate, and share information; and to track all the resources. The logistic section provides the supplies, needs, and the facilities and supports the personnel with food, water, and first aid. The finance/administration section is in charge of tracking all the costs and to negotiate and supervise contracts.

These sections, like the ICS, are modular organizations and can be further expanded into: units (the organizational element with functional responsibility for a specific incident planning, logistics, or finance/administration activity), divisions (only for operation section, used to divide an incident geographically), groups (only for operation section, established to divide the incident management structure into functional areas), and branches (used when the number of divisions or groups exceeds the span of control and can be either geographical or functional for major aspects of incident operations) [21].

Triage

Triage in a disaster event places casualties in four classes: black (or expectant), red (or immediate, priority 1), yellow (or delayed, priority 2), or green (or minor, priority 3) in agreement with the severity of the injuries. When sorting casualties, it is important to give immediate medical care to critical patients that have a chance of survival with prompt, advanced treatment. In minor patients and patients who are so severely injured that they have very little chance of survival treatment is delayed. The goal is to provide the greatest good for the greatest number of patients, forcing the triage officer to decide whether the chance of a patient surviving is so low in comparison to the burden such care would place on the medical system that the patient must be consigned to the “expectant” category (dying; little or no treatment) [22].

The concept of triage must be seen in a wider context and is composed of the following elements: rapid evaluation of all disaster victims, assessment of the nature and severity of the injuries and its consequences on the vital functions of the casualties, and categorization of the casualties, resuscitation, stabilization, and conditioning for transport, distribution, and evacuation of the casualties [23].

Triage is a quick and dynamic process. This means that it must be repeated often and at every moment in which a new healthcare professional takes control of a patient, for example, during transport, at arrival at the hospital, or if there is the suspicion that the state of the patient has changed. Triage will be discussed further in the Chap. 26.

“Second Hit” Phenomenon

The “second hit” is a classic tactic and pattern seen in terrorist attacks. It is defined as second incident caused by the terrorists, following the first event, with the goal of striking the first responders that are on scene. Typically, it is a second explosion close to the scene and often more powerful than the first detonation. This is because the intention is to create casualties during the first blast and to attract people to the scene and then striking them with a larger detonation. This achieves the goal of a terrorist attack: to cause additional chaos thereby delaying the response and causing great physical and psychological impact on the populations and on the rescuers.

An example of this was the terrorist attack in 2002 in Bali. Two bombs detonated within a short period of time. The first was concealed in a vest worn by a suicide bomber. The second charge was in a minivan about 15 m away when the first explosion happened. The force of the car bomb was enormous [24].

Terrorist attacks are very challenging and difficult to manage, because they are designed to create loss of life and property damage, disruption of the agencies involved in the response, and fear and harm to the population.

The Israel response system is very seasoned to terrorist attack and has specific guidelines and protocols in case of attacks to avoid damage from a “second hit.” Traditionally, medical teams do not enter the scene of the explosion until it is deemed safe by police or army personnel. With many of the terrorist attacks in Israel, a secondary explosion or bomb is set off timed to cause additional injuries to the emergency personnel and bystanders responding to the primary event. However, because time is critical, often EMS does not wait for such security clearance and attempts to rapidly remove the casualties from the immediate vicinity of the initial event. The only medical care given before this initial evacuation is external hemorrhage control [25]. They apply the “scoop and run” approach on the scene (minimal resuscitation on the scene and immediate transportation to the trauma center) to clear the casualties from the area of the event but in the meantime minimize the risk for the rescuers. Therefore, in case of a terrorist attack, it is imperative to maintain the role of the incident commander, the coordination between the agencies, and training of the rescuers to guarantee the safety of all the workers involved in the response.

Key Points

- Disaster is defined as any event that causes serious disruption of society which exceeds the ability of the affected community to cope using its own resources.
- Disasters are usually categorized as natural or man-made, and response to them follows the same pattern, called the disaster cycle, defined in four phases: mitigation and prevention, preparedness and planning, response, and recovery.
- The Incident Command System (ICS) is a standardized and modular organization, on-scene, and all-hazards incident management concept and allows its users to adopt an integrated organizational structure to match the complexities and demands of single or multiple incidents.
- The word triage means "to categorize, to sort." The purpose of triage in a disaster event is to catalogue the casualties in agreement with the severity of injuries. Sorting casualties is important to give immediate medical care among critical patients that have a chance of survival. The goal is to provide the greatest good for the greatest number of patients.
- The "second hit" phenomenon is a classic tactic and pattern of terrorist attacks. It is defined as a second incident caused by the terrorists, a little bit later than the first event that is geared to injure the first responders that are on the scene.

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The Multi-casualty Trauma

26

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Introduction

Multi-casualty trauma following unexpected natural and human-made disasters creates major stress on receiving hospitals and regional trauma systems as local emergency services attempt to treat multiple seriously injured victims simultaneously. However, the strain of a multi-casualty trauma event remains within the confines of an institution's surge capacity to adequately manage all patients. This is in contrast to "mass-casualty trauma (MCT)," where the required resources exceed the surge capacity of a single institution and at times the trauma system as a whole. Therefore, it is the availability of local and regional resources to the event, and not the absolute number of victims, that differentiates a *multi-casualty trauma* from a *mass-casualty trauma*. Timely and effective coordination of all available resources at the local and the regional level is critical when attempting to manage the varying number of patients in such events.

The purpose of this chapter is to discuss principles of triage during MCT, describe the various components of the response team and their roles during such events, and discuss the role of simulation training to prepare health-care personnel for unexpected MCT.

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Historical Perspective

While MCT have existed for centuries, priority of care was often given to patients depending on rank, socioeconomic status and specific nationalities, without taking into account the severity of injuries [1]. As outlined in the previous chapter, it was not until Baron Dominique Jean Larrey, Surgeon-in-Chief of Napoleon's Imperial Guard, and the French Service de Santé coined the term "triage" (meaning "to sort") and began to systematically organize the care of patients during MCT [2]. Larrey's triage system, along with his horse-pulled ambulances, allowed him to treat patients according to the severity of their injuries, similar to principles used in today's modern triage systems.

Ethical Issues in Multiple Casualty Trauma

Health-care workers are often confronted with ethical dilemmas while managing a MCT. Often times, first-responders who arrive at the scene place their own lives at risk while attempting to help victims. Hostile environments include urban zones in the aftermath of natural disasters (such as earthquakes and hurricanes), where buildings are still at risk of collapsing, or a district that has suffered terrorist bombings and is at risk of subsequent explosions. For instance, during the 9/11 attack, 343 fire fighters lost their lives while attempting to rescue victims [3]. The duty to treat and to put oneself in harm's way during disasters often contradicts one's duty to themselves [4].

Another ethical issue commonly associated with MCT is determining which patients receive priority care. Under normal circumstances, triage in the emergency department prioritizes which patients receive care first. When multiple

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casualties are involved however, not every patient may receive immediate medical attention [5]. This requires good judgement by health-care personnel to make decisions which are not always easy to make. Resource-allocation is often done in the context of three key principles [6]:

1. Utilitarianism—"the greatest good for the greatest number".
2. Principle of equal chances—"first come, first served".
3. Egalitarianism—"those most in need should receive".

Utilitarianism normally takes precedence over other principles in MCT, since the primary goal is to treat the greatest number of victims in the best possible way. Often, the response team needs to make difficult and timely decisions regarding the allocation of resources to a patient depending on their "salvageability". Personnel in charge of triage should therefore be cognisant of the utilitarian principle governing MCT in order to avoid any interference with a systematic and effective resource-allocation protocol.

Prehospital Management

Triage

Triage, a fundamental concept in the management of MCT, involves sorting the wounded according to the severity of their injuries and assigning treatment priorities in the context of available resources for a relatively large patient load. This is a paradigm shift compared to normal circumstances, where an assumption is made that adequate resources are available for everyone.

In a typical MCT, it is estimated that 10–15 % of victims will sustain severe injuries, while the remainder will suffer mild to moderate traumas [7]. The primary objective of the triage process is to identify the subset of victims who are both severely injured and salvageable, and transfer them to a trauma center in a timely fashion. Identifying this priority group can be quite challenging. Due to the number of patients presenting simultaneously during MCT, rather than focusing on each injured patient individually, personnel in charge of triage focus their attention on the entire injured population [8]. Both severity of injuries and degree of salvageability of patients should be taken into consideration when deciding how to allocate resources, with the aim of saving as many lives as possible. Other factors that should be taken into consideration include the total number and nature of the wounded, the geographic location, available facilities and personnel, lines of evacuation, and transport duration. To assist with objective decision-making, several triage tools have been developed.

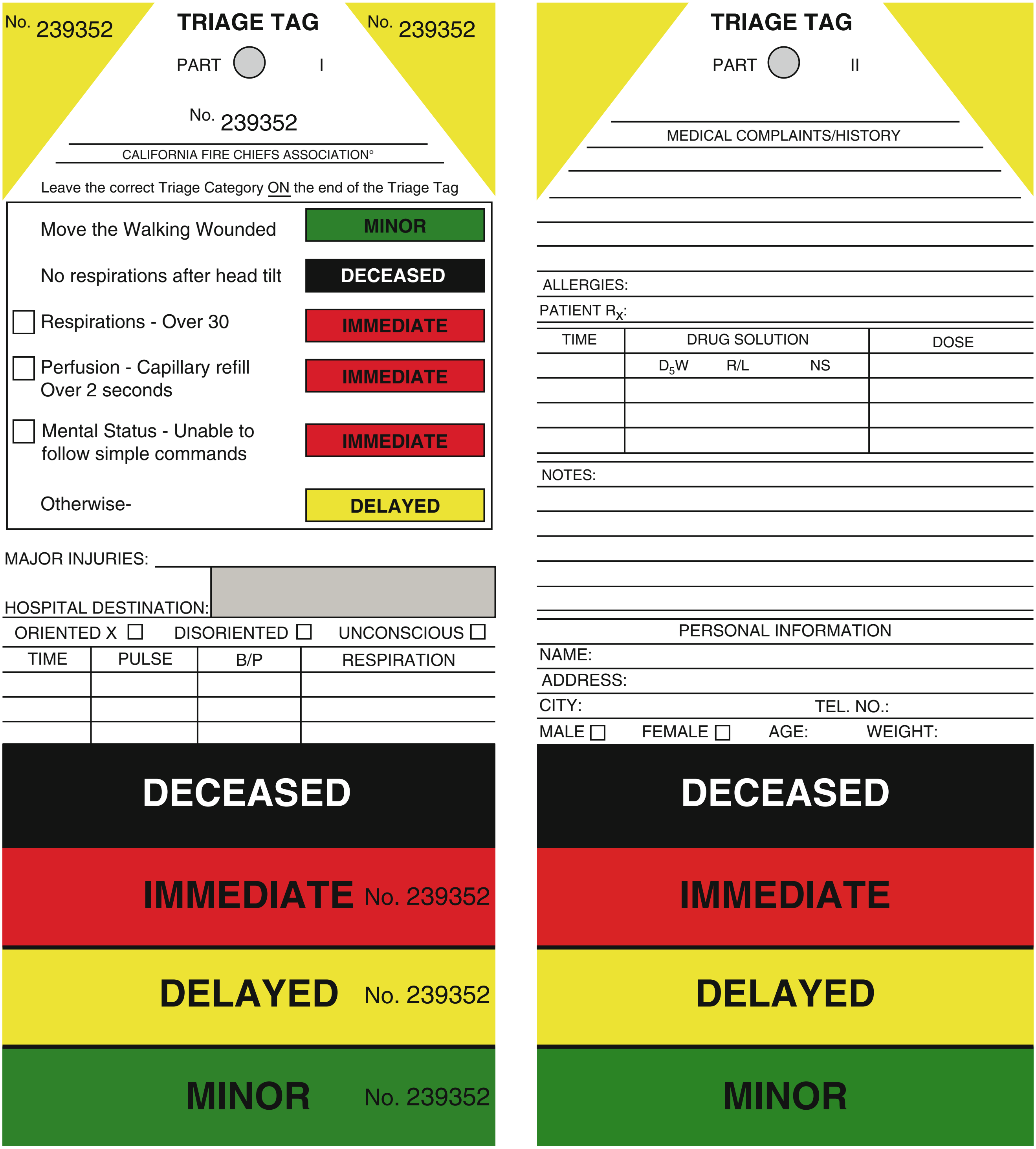
The process of triage is not a single event. Instead it is continuous and patients are consistently reevaluated. It is imperative that decisions be respected with optimal teamwork and communication. The triage process can be categorized as following:

- *Primary triage* is performed at the scene of the event, normally by paramedics or first-responders.
- *Secondary triage* is performed at the facility where patients are transferred, typically at the entrance of the emergency department by the most experienced health-care professional, usually an experienced surgeon or emergency physician. Based on the level of care required, injury severity of the patient and the resources available, the patient is moved to a predesignated area where further appropriate care is provided.
- *Tertiary triage* is performed by surgeons, emergency physicians, anesthesiologists, or intensive care physicians in order to determine where in the hospital the patient should be transferred. The intensive care unit (ICU), operating room, radiology suite, and a designated "minor" care area are some of the most common destinations. Based on available human resources and severity of injuries, the following are done: vital signs measurements, intravenous line placement, initial resuscitation, administration of antibiotics and tetanus vaccine, obtaining blood work, and preparation for transfer.

Ultrasound (Focussed Assessment with Sonography in Trauma (FAST) or "extended" FAST) can be an effective tool that may help during tertiary triage. Use of ultrasonography in a mass casualty scenario was described by Sharkisian et al. following the 1988 American earthquake. More recently, the use of FAST in multiple casualty scenarios was described in a retrospective Israeli study that showed that FAST enabled immediate triage of casualties to laparotomy, CT, or clinical observation, with a positive predictive value of 88.2 %, negative predictive value of 94.1 %, and accuracy of 93.1 % [9, 10].

Effective triage should be accompanied with a simple patient identification system that is unambiguous and understandable by all health-care personnel. Each patient should be tagged with a visible triage card containing their demographics, medical assessment and triage allocation (Fig. 26.1).

Despite timely triage efforts, there exists the possibility of patients either receiving less than the level of care required to treat their injuries (under-triage), or receiving more than the level of care required (over-triage) leading to inappropriate utilization of limited resources (e.g., transportation, beds, imaging modalities). A less than 5 % under-triage rate and less than 50 % over-triage is generally acceptable [11].


No. 239352 TRIAGE TAG No. 239352
PART I
No. 239352
CALIFORNIA FIRE CHIEFS ASSOCIATION©
Leave the correct Triage Category ON the end of the Triage Tag

Move the Walking Wounded	MINOR
No respirations after head tilt	DECEASED
☐ Respirations - Over 30	IMMEDIATE
☐ Perfusion - Capillary refill Over 2 seconds	IMMEDIATE
☐ Mental Status - Unable to follow simple commands	IMMEDIATE
Otherwise-	DELAYED

MAJOR INJURIES:
HOSPITAL DESTINATION:
ORIENTED X ☐ DISORIENTED ☐ UNCONSCIOUS ☐

TIME	PULSE	B/P	RESPIRATION

DECEASED
IMMEDIATE No. 239352
DELAYED No. 239352
MINOR No. 239352

TRIAGE TAG
PART II
MEDICAL COMPLAINTS/HISTORY
ALLERGIES:
PATIENT R_X:

TIME	DRUG SOLUTION	DOSE
	D_5W R/L NS	

NOTES:

PERSONAL INFORMATION
NAME:
ADDRESS:
CITY: TEL. NO.:
MALE ☐ FEMALE ☐ AGE: WEIGHT:

DECEASED
IMMEDIATE
DELAYED
MINOR

Fig. 26.1 Multi-casualty trauma patient identification and triage tag utilizing a color code to indicate the level of care needed based on the Simple Triage and Rapid Treatment (START) system. Reprinted with permission from the California Fire Chiefs Association

Because triage decisions can be difficult and at times emotionally challenging for health-care personnel, the triage officer should be someone of authority, well-respected, and not only knowledgeable of patterns of injury but also must have a very clear understanding of all resources available at any given time.

"START" System for Triage

In order to assist with the on scene primary triage process, several tools have been developed to allow for a timely and objective decision-making. This includes the Simple Triage And Rapid Treatment (START) system, initially created in 1983 by the Newport Beach Fire Department in California. This system is easy to use and focuses on patient physiology, providing a rapid assessment for each patient which lasts no more than 30 s. Using the START protocol therefore permits very few rescuers to rapidly triage a large number of patients, which is invaluable for multi and mass-casualty traumas.

Patients are initially designated a color depicting the level of care needed (Fig. 26.1):

- Red: immediate care.
- Yellow: delayed care.
- Green: ambulatory care.
- Black: deceased.

Initially, walking patients are identified, tagged as green (i.e., ambulatory care) and directed to a designated area for detailed assessment and treatment. Ambulatory care patients can also assist first-responders.

Assessment for non-ambulatory patients should subsequently focus on patient physiology, including respiration, perfusion, and mental status.

- *Respiration*:
  - Patients who do not breathe spontaneously despite opening the airway manually are designated as black (i.e., deceased).
  - If patients breathe spontaneously at a respiratory rate greater than 30 per minute, or initiate spontaneous breaths after the airway is opened manually, they are designated as red (i.e., immediate care).
  - Patients with spontaneous respiration at a rate less than 30 per minute should undergo perfusion assessment.
- *Perfusion*:
  - Patients with either absent radial pulse or capillary refill longer than 2 s are designated as red (i.e., immediate care).
  - If both radial pulse is present and capillary refill is less than 2 s, the patient's mental status should be assessed.
- *Mental status*:
  - Patients who cannot follow simple commands, are unconscious or have altered mental status are tagged as red (i.e., immediate care).
  - All other patients, whose respiration, perfusion and mental status are non-remarkable, are tagged as yellow (i.e., delayed care).

Red patients require immediate care and should be transferred as soon as possible, after addssing either an upper airway obstruction or controlling obvious hemorrhage. Patients tagged black should be reevaluated once interventions have been performed for red and yellow patients.

Multiples validation studies have been performed using START. Gebhart et al. [12] evaluated the START algorithm on trauma patients, showing strong efficacy. An important point to highlight is that patients tagged as black during multi-casualty traumas may receive a level of care that is very different than if that same patient were to arrive to the emergency room on any other day. For instance, a patient without spontaneous breathing after a trauma typically requires a definitive airway (normally with endotracheal tube intubation). When the START protocol is activated, this same patient might be tagged as black and thus considered unsalvageable. Several authorities have suggested that, given resources are overextended and not overwhelmed in multi-casualty trauma, patients have more access to definitive care compared to mass-casualty traumas. The use of the START tool should therefore be discouraged in these situations to avoid under-triaging patients. Other triage methods have been introduced, including the Sacco Triage Method (STM) and the Fire Department of New York (FDNY) method. While triage methods should focus on predicting clinical priority, most studies comparing triage tools have instead focused on their ability to predict mortality [13]. Further studies will be required to determine which tools are most appropriate during multi-casualty traumas.

Pediatric Considerations

In MCT, special considerations during triage should be given to the pediatric population. The JumpSTART algorithm is used to triage children under 8 years old (this algorithm can be retrieved online from http://www.jumpstarttriage.com/uploads/Combined_Algorithm.pdf).

Children who can walk independently are designated as green and subsequently undergo a secondary triage. Similar to the adults START algorithm, all other patients are evaluated based on their physiologic status, including their breathing, perfusion and mental status.

- *Breathing*:
  - If patient is apneic or has irregular breathing, the airway is opened manually. Patients in whom spontaneous respirations resume are designated as red (i.e., immediate care). If spontaneous respirations do not resume *and* patients do not have a palpable radial pulse, they are designated as black (i.e., deceased).
  - Apneic patients with a palpable pulse should receive five rescue breaths. If apnea persists, they are tagged black, and if breathing resumes, red.
  - Patients with respiratory rate either less than 15 per minute or greater than 45 per minute are designated as red, while those between 15 and 45 per minute should undergo perfusion assessment.
- *Perfusion*:
  - Patients with either absent radial pulse or capillary refill longer than 2 s are designated as red (i.e., immediate care).

  - If both radial pulse is present and capillary refill is less than 2 s, the patient's mental status should be assessed.
- *Mental status*:
  - Assessed using the AVPU (Alert, Response to verbal stimulus, Pain, Unresponsive patient) scale.
  - Patients who inappropriately respond to pain or are unresponsive are tagged as red (i.e., immediate care).
  - Patients who are alert or responsive to verbal commands or pain, are tagged as yellow (i.e., delayed care).

Patient Transportation and Allocation Within the Trauma System

Following the initial primary triage, patients are transferred to an appropriate hospital for definitive management. Although lines of evacuation can be predetermined for disaster events leading to multi-casualty trauma, they often need to be established during the disaster itself. For instance, after natural disasters such as earthquakes or hurricanes, roads can be entirely destroyed, creating significant and unanticipated challenges when attempting to evacuate and transport victims.

Appropriate allocation of patients to different trauma centers is an important part of multi-casualty trauma management. All available health-care facilities within a reasonable distance from the event, including level 2 trauma centers and community hospitals, should be utilized by the dispatch team. This strategy will avoid overcrowding level 1 trauma centers. On the other hand, underutilization of level 1 trauma centers should also be avoided. Gill et al. compared their trauma system's response to two multi-casualty trauma train crash disasters which occurred in 2005 and 2008. Post-crash analysis after the initial 2005 event showed that most victims were transferred to local community hospitals while trauma centers were underutilized. Improving the system by which patients were allocated to various regional institutions based on injury severity and needs, demonstrated an improvement in the distribution of victims in the subsequent 2008 train crash [14]. Novel computer-based models to support patient allocation have recently been developed, which take into account variables such as road traffic, hospital capacity, and hospital capabilities [15]. A thorough understanding of one's regional trauma system and consistent communication amongst all personnel involved in trauma care is necessary to provide effective and timely patient care.

Independent predictors of evacuation to dedicated trauma centers include being the hospital closest to the event, evacuation within 10 min of the event, and having a patient requiring urgent care in the ambulance [16]. Ideally, patients with more severe injuries should be transferred to level 1 trauma centers where they can receive definitive care, instead of the nearest hospital. Transferring these patients to a level 2 trauma center will only delay definitive care. Conversely, patients who have sustained less severe injuries should be transferred to level 2 or 3 trauma centers, where they can be adequately treated for their injuries. This will prevent overcrowding level 1 trauma centers with patients who can receive satisfactory care elsewhere.

Intrahospital Management

Although first-responders have initiated primary triage at the scene of the disaster, resources within each hospital should begin to be mobilized immediately in preparation for the patient load and surge capacity of their facility. Resources include anesthesiology, intensive care unit (ICU), operating room, trauma team, emergency department, and blood bank personnel, as well as the availability of beds, resuscitation equipment, imaging modalities, transportation, and communication systems. The hospital incident commander should be working with senior hospital administration to help manage resources in an effective manner.

Secondary triage takes place at the emergency department entrance by a designated triage officer. The triage officer should be consistently receiving feedback from the field units regarding the expected patient load, as well as from in-hospital staff to determine the conditions within the hospital. This two-way feedback allows the triage officer to manage available resources effectively. The triage area should be equipped with essentials such as stretchers, blankets, dressings, intravenous fluids, plasma expanders, respiratory support equipment, and other equipment normally used in the trauma bay.

Far less literature exists on how to triage patients following multi-casualty traumas once they pass through a trauma center's doors, compared to prehospital triage. At our institution, following the Dawson College shooting in 2006, triage was done using a combined anatomic and physiologic classification based on the location of the injury and signs of physiologic instability [17].

- Green: stable walking wounded.
- Yellow: complex extremity wounds needing neurovascular assessment.
- Red: thoracoabdominal injuries and patients with hemodynamic instability.
- Black: Gunshot injury to the head.

The city of Montreal suffered three multiple shooting incidents over the last 20 years. The last of such events occurred at the Dawson College in downtown Montreal with 15 victims, 11 of which were transferred to a level 1 trauma center. Analysis of the event revealed that hospital capacity was sufficient for all patients to receive adequate care, including accommodation of five more operating rooms and ten more ICU admissions, with no in-hospital mortalities. This system of anatomic and physiologic classification proved to be an effective system for in-hospital triage at a trauma center to assign patients rapidly to appropriate care.

During the multiple casualty event of the Dawson shooting, the Montreal General Hospital was fortunate to have many individuals available to assist (including physicians, nurses, orderlies, allied-health workers, medical students, and others). If not managed appropriately, this can lead to overcrowding of health care personnel and inefficient care. While it is important to take advantage of all manpower available, this should be done in an organized fashion, directed by the appropriate leadership. Teams consisting of one surgeon, house staff, and nursing were created to tend to each victim arriving following the school shooting in 2006.

Transfer Corridors

Access to hospital emergency services, for both trauma and non-trauma patients, should be limited to one entrance at the ambulance arrival zone. All admitted patients should have an identification tag, similar to the one given during primary triage, with their name or a given number to assist with management and reassessment. Official hospital registration typically occurs at later stages.

Patients in the emergency department prior to the multi-casualty trauma should be transferred to an adjacent zone, with pre-designated physicians, paramedics, and nurses. These patients can continue to receive necessary care, while attempts are made to either discharge or transfer them to the appropriate ward or to another hospital if possible. Furthermore, daily emergencies unrelated to the multi-casualty trauma, such as cardiac arrests, surgical emergencies, and obstetrical emergencies, should be diverted to other secondary non-trauma hospitals.

Blood Bank

Blood banks play an important role during a multi-casualty trauma. Although the blood banks of trauma centers are able to cope with multi-casualty trauma depending on the number of casualties, it is important to have a surge capacity to respond to such events. When all casualties are taken into account, some authors describe the need for on average 1.3 units of red blood cells and 1.0 units of component per patient [18]. With many patients needing transfusion at the same time, efforts should be made in patient identification to avoid mistransfusions; use of wrist bands, barcode tagging or other devices can help to avoid this problem [19]. Protocols should also include how to manage the large number of blood donors that may arrive after an event, wanting to donate blood. After the 9/11 attack, in spite of collecting 500,000 units of blood after an American Red Cross appeal, many of the collected units where analyzed and categorized as non-usable [20]. This highlights the importance of maintaining a high standard of quality control with donated blood despite the possible immediate need of large amount of blood products to respond to a disaster.

Staff-Recalling Systems

The hospital should have an organized system to allow timely contact of essential staff to assist with the multi-casualty trauma. Any situation involving breakdown of communication infrastructure, (ie) when natural disasters occur, or disasters occurring during the night or on weekends when staff are not in-house) makes it difficult to recall essential personnel. Regular updating of contact information, testing and analysis of responses to simulated disaster alerts should be done periodically [21]. Each hospital should also have a tested communication system that best suits its needs, using pagers, mobile phones or other devices.

Intensivists and Anesthesiologists

Intensivists and anesthesiologists are important resources and play important roles alongside surgeons and emergency physicians during a response to multi-casualty trauma, by having the capacity to manage severely injured patients with advanced resuscitation skill and equipment (such as mechanical ventilators).

Forward deployment systems, involving the use of one anesthesiologist to provide continuity of care for each patient has been shown to be effective [22]. After initial assessment by the trauma team, the anesthesiologist can accompany the patient throughout other levels of care, including the trauma bay, radiology suites, and operating room if needed. If the patient is taken to the operating room, the anesthesiologist has a thorough understanding of the patient, which is especially useful when multiple specialties are needed at different stages in the operating room. This model has the advantage of keeping the surgeons in the emergency department to assess and manage incoming patients or proceeding directly to the operating room for patients who need immediate surgery.

In multi-casualty trauma, ICUs are typically one of the first resources to be saturated. Under normal circumstances, they are fully occupied with critically ill patients, making it difficult to maintain a high surge capacity. It has been reported that 4.7 % of multi-casualty trauma patients will require ICU admission, 73 % of which will require mechanical ventilation [23]. Intensivists should be actively involved in multi-casualty trauma, having direct communication with the hospital incident commander, trauma team leaders, and anesthesiologist in charge to effectively manage ICU beds, ensuring the required number of beds are liberated for incoming patients. The use ICU resources across the region are an important component in any disaster response planning. During the 2006 Dawson College shooting in Montreal, the ICU at the level 1 Trauma center immediately initiated protocols to transfer hemodynamically stable patients already in the ICU (both medical and surgical patients) to non-trauma center ICUs to liberate capacity to accommodate incoming victims.

Finally, it is important to have a clear inventory of all potential places within the institution, outside of the ICU, where critically ill ventilated patients can be accommodated as surge capacity. Such areas may include postoperative recovery rooms, post-procedure recovery rooms, coronary care units, and even procedure rooms such as day surgery and interventional cardiac suites.

Training, Simulations and Preparing for MCT

The use of simulation has recently gained significant momentum, allowing trainees to learn in a controlled environment free of any adverse consequences to patients, reach proficiency faster, and improve overall performance. The recent Boston marathon bombing is a great example of how the use of simulation and drills prior to the event can help prepare the response team for multi-casualty trauma. Although three patients were killed that day, all the three died before reaching the hospital. The effectiveness of the response to this tragedy has been largely ascribed to the deliberate preparatory actions that were taken prior to this event, leading to rapid response of first responders, field triage, and delivery of care in trauma centers [24]. For instance, in 2002, the city of Boston simulated a large-scale disaster drill, with one of their main hospitals receiving 72 simulated patients (compared to the 39 casualties during the marathon bombing). During the following years, 73 exercises were performed, including communications and power failure drills, and a mass casualty bombing drill in 2010. Apart from drills, the city also analyzed multi-casualty trauma events occurring in other cities, and initiated trauma team training with physicians, nurses, and administrative personnel. The use of simulated drills, including all personnel involved in a multi-casualty trauma, improved the performance of the response team on the day of the bombing. Having training assessments help communications and triage performance [25], and tests how the system is working and its pitfalls. The use of large-scale simulations is resource-intensive and challenging. However, done periodically, it allows us to test various levels of the response to multi-casualty traumas, while having a disaster committee identify and improve weaknesses. It is important to recognize that simulation is crucial not only for front-line health care workers, but for every component of the system, including law enforcement, hospital administrators, patient transport, patient attendants, housekeeping, equipment/supply replenishment personnel, and even food services.

Debriefing

Once all patients have been transferred to the hospital and initial treatment plans have been provided, debriefing allows the entire team to be updated on the situation—both in and out of the hospital. Meeting with the team after the initial chaos also provides a sense of unity and helps to reorganize available resources. After the Montreal 2006 Dawson College shooting, the overall performance of our trauma center and system was reviewed via numerous multidisciplinary team debriefings. These debriefings and a careful review of each case revealed areas of strength and weakness that may prove to be useful to trauma centers that may have to deal with such unfortunate events in the future.

Last, but not least, debriefing should also center on the psychosocial aspects, including posttraumatic stress disorder (PTSD), that can be suffered by the medical teams and emergency medical service personnel. As described by Lubin et al., health care personnel should receive constant training on how to cope with these situations, and have the appropriate psychosocial support following an event [26].

Conclusions

Multi-casualty trauma is thankfully a rare occurrence in most trauma systems. Nonetheless, adequate preparation, training and simulation are essential for all those involved. A well-structured system can help mitigate the intense chaos and confusion that undoubtedly accompanies these events, and can ultimately lead to better outcomes for all injured patients.

Key Points

- Multi-casualty traumas following unexpected natural and human-made disasters create major stress on receiving hospitals and regional trauma systems.
- Timely and effective coordination of all available resources, including those in the prehospital and intrahospital settings, is critical when attempting to cope with the patient load.
- Effective and objective triage is paramount in multi-casualty trauma.
- Institutions should be familiar with their surge capacity.
- Adequate preparation allows for an effective and coordinated response to unexpected multi-casualty trauma.

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Critical Incident Team Dynamics and Logistics

27

Brian P. Smith, Jonathan Mulhern, Kevin Glenn, and Lewis J. Kaplan

Introduction

The interplay of internal coordination and member cohesion with the extrinsic forces of chaos, stress, and unpredictability underscores the need to understand and develop high-functioning teams to succeed during critical incidents [1]. This concept is termed critical incident team dynamics and enjoys substantial overlap with team logistics. The successful functioning of teams that perform in high-stress and unpredictable environments with unpredictable timing (critical incident team) hinges on training in such a way that requisite skills are developed and enhanced. Performance is continually assessed and improved, thus establishing a competency-based hierarchy that can function within a fluid environment. The methods by which to assemble, select, train, and review such teams rest on scientifically sound principles that will form the thrust of this chapter's exploration. This chapter seeks to provide a readily understandable and deployable blueprint for team administrators, liaisons, leaders, as well as members.

Crew Resource Management (CRM)

As discussed in Part I of this text, the goal of CRM is to ensure the success of teams through reduction of human error [2, 3]. A formal approach to team development is essential since the unexpected will occur, and for trauma teams as well as law enforcement agencies, failure to operate efficiently can lead to loss of life as well as substantial and potentially avoidable morbidity. Crew resource management works to control human factors to the greatest degree possible; to remove their influence forms the calculus of success. Teams that benefit from CRM are those that operate in environments where unknown external forces continually affect the executed plan. For instance, airline crews, the firefighting industry, oil rigging, and, pertinent to this book, police and healthcare workers often employ CRM methodology when developing service lines [4].

Another hallmark of CRM is the establishment of a culture of safety where all team members, regardless of rank or tenure, are empowered to voice concerns and engage in process improvement. Essential elements include promoting situational awareness, problem identification, decision-making for problem resolution, effective and equitable workload distribution, time management, and conflict resolution (a learned skill that relies on courtesy, respect, and trust) [5, 6]. The above processes help define the atmospheric tone of the organization, a feature that strongly influences the likelihood that individual members will feel comfortable enough to challenge the status quo in search of excellence. CRM works if it is embedded in the organizational structure, inaugurated with each and every project and task, iterative in nature, and modified and improved using hard data [7]. A prime example of the successful application of these

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principles is the airline industry and military special operations teams [8–10]. In each example, the organization is continually improved by empowered individuals whose goal is continual process improvement as failure is indeed not an option. Crisis is the crucible whereby the success of CRM is measured.

Characteristics of Crises

Critical incidents qualify as crises since they are emotionally charged, stressful, and unanticipated events that presage abrupt and often undesired change. Many events represent critical incidents including natural disasters (hurricanes, floods, etc.), mechanical disasters (plane crashes, bridge collapses, etc.), and civilian police-related events. Wars have some features of critical incidents but are differentiated by having a slower pace toward change and are more, rather than less, anticipated. Crises are different from conflicts in that conflicts represent the opposition of two different wills rather than physical events. Understanding the five hallmarks of crises allows for optimization of successful management strategies (Fig. 27.1).

First, confusion is a hallmark of crisis in that there is information and plan disarray, and crises are unclear in nature and course. Confusion impedes obtaining useful and timely information regarding current events. Second, all crises are imbued with risk which may oppose decisive action. Third, since crises are unexpected, they represent a unique and transient concatenation of circumstances, individuals, and locations, establishing a time sensitivity to their solution. When the crisis involves individuals, the crisis may be characterized as time competitive in that the commander needs to maintain the initiative to reach a rapid and successful resolution. Fourth, even when individuals are not the focus of the crisis, there is a human element centered about the responders and victims that must be acknowledged both during and after the crisis is resolved. Fifth, tactical crises powerfully tend to degenerate toward chaos. Effective teams that are integrated into highly functional systems provide the main mechanism to resolve, but not prevent, critical incidents.

Fig. 27.1 Crisis characteristic

Key Elements of Team Dynamics

Even great leaders cannot craft a superb team if the membership is not up to the task. Membership selection is therefore a key event. There is no single metric that will allow a leader to select ideal team members, but a montage of metrics may well serve to do so [11]. Performance metrics that highlight dedication, drive, and aptitude are useful. Physical fitness assessment is another required element when selecting team members for high-speed team such as SWAT teams [12]. The Cooper Institute Fitness Assessment is a commonly used instrument that has been validated as a predictor of a police officer's ability to complete patrol duties [13]. However, it is less rigorous than measures employed by US Military Special Operations Teams during member selection and performance review. The latter is a key element that is often overlooked, especially in low-activity (i.e., infrequent SWAT team call-outs) regions with dually tasked individuals (patrol officer and SWAT operator, firefighter and urban search and rescue operator, etc.) [14]. Instead, iterative assessment is required for team membership. The military special operations teams have the benefit of continual assessment during deployments as well as between deployment training sessions. Indeed, fitness is part of the job description, and time is allotted for fitness maintenance; no such time is generally allotted for civilian special response team members, and such activities are generally not funded. Fitness is therefore the responsibility of the team leader and team members.

Command and Control

The notion of command overlaps with the concept of control. It is useful to distinguish the two as they are not necessarily embodied in the same individual. Command identifies that the individual can (by virtue of their position, power, and authority) compel compliance. Control implies that the individual is providing direction but cannot compel adherence to their plan. Control is enabled by persuasion, influence, and example. Both command and control are inextricably intertwined in critical incidents [1]. Indeed command is said to have delegated authority, while control is said to represent perceived authority. Military parlance denotes the two as C2.

Team commanders may be selected on the basis of perceived or demonstrated skill in related or unrelated domains. Real-world experience (immersive, direct) is always preferable to tenure-based (inferred) experience [15, 16]. Commanders and team leaders need to maintain the initiative during critical incidents so as to direct the interrelated events necessary for resolution. This task is optimized by crafting an appropriate command and control architecture.

Command and Control Architecture

Since critical incidents are temporary, command and control architecture is similarly temporary. Embracing the need to have a single command entity, such temporary architecture should be explicitly constructed to be directed by a single entity. Such constructs may be typified by Emerging Multi-Organizational Networks (EMON) which consist of task-oriented and mission-specific collaborations of individuals and resources [17, 18]. EMON structure defines lines of authority (effectively but not necessarily equitably), distributes power, and efficiently allocates resources for critical incident resolution, broadly grouped into the following eight domains:

1. Common technology and procedures.
2. Modular development of teams and responses.
3. Unified command structure.
4. Plan in advance for every major and predictable type of critical incident the team might face, as well as recovery plans for initial plan failure or inefficacy during an incident.
5. Maximum number of supervised individuals.
6. Identify critical incident relevant facilities.
7. Resource management plans for all teams.
8. Integrated communication systems.

Communication systems pose a unique challenge to EMON structure as these events oftentimes involve disparate elements, integrating different communication systems and protocols. The most effective team is likely to fail if the parts are unable to communicate in a timely and effective fashion. One such example is the Area Command Team (ACT) concept of the LA County Sheriff's office. Following the 1992 Los Angeles riots, the LA County Sheriff's Department completed an in-depth review process that evaluated the logistics behind their successful and unsuccessful resource management that laid the foundation for modern management paradigms. The ACT concept has articulated structures that parallel how SWAT teams function today including a central command with linked field command coupled with teams with operational authority in response to conflict exigencies that depart from the anticipated course. Such a structure is readily adapted to nonpolice command team structures as well. Effective ACTs require resources to be funded and allocated for team use.

Resources

Resource management includes acquisition, cataloging, maintenance, revision, funding, allocation, mobilization, and deployment of needed elements in a fashion designed to swiftly resolve the critical incident. Therefore, resource management includes not only material but human resources as well. Since critical incidents often span more than one responder type (i.e., police, SWAT, EMS, fire), a system for resource management is essential. Resources can be housed at a single depot location or mobilized from various staging locations as needed. Both approaches work and selection of the most appropriate method should be influenced by local dynamics. An oft underappreciated aspect of resource management is team member development [9]. This includes ongoing training and advanced training of existing members as well as recruitment and education of new members. A plan for ongoing team development to include succession planning would also be appropriately housed under resource management. Regular review of all of the above elements helps teams and their administrators determine how best to manage all aspects of their teams.

Review Process Including Logistics

Developing and maintaining a review process that evaluates team construction, resource allocation, and coordination within an agency as well as with other agencies should be distinct from the review process that evaluates team performance during critical incident deployment. The first relates to funding and the mechanics of relationship development, while the latter addresses real-world implementation of what the former has put in place. An essential element of the review process is to identify the presence of gaps in logistics for critical incident response and coordination. A templated approach to the review will support a regular process and should be constructed to identify elements that are missing and deficient in number or extent, as well as those that are ideal. Best practices that may be exported or taught to other agencies should be identified and should be considered for dissemination at multiple levels. Agency templates should have broad overlap of general domains (Fig. 27.2). The domains may include, but are not limited to:

1. Commander, leader(s), and team members (number, training, and capabilities)
2. Tools and equipment
3. Communication (equipment and protocols) and mobile platforms
4. Computer and information technology infrastructure and architecture
5. Intelligence gathering/analysis and dissemination
6. Training time and scope

Fig. 27.2 Agency template domains

7. Standard operating procedures and memoranda of understanding with relevant agencies, policies, and protocols
8. Threat matrix-driven team deployment triggers and succession planning

The review process and logistical evaluation are thorough and redundant plan that optimizes strategy and resource allocation to ensure that all essential elements are available and accessible during critical incidents.

Transactive Memory

Transactive memory is a characteristic of successful teams that results from iterative training with the team as a whole [19]. Each team member understands their role as well as that of the other team members. Integrated training exploits the expertise of each team member and makes it clear to the other members of the team. An external reviewer might note smooth performance without significant need for communication to address challenges. Such observations characterize special operations teams that continually practice, train, and deploy together. Civilian teams rarely do so to such a degree, and many elements that are mobilized during a critical incident are accustomed to working alone rather than as part of a dynamic team (i.e., patrol officer who is the first responder to an active shooter scenario). Thus, the cultivation of transactive memory must be a fundamental goal of team training and may change throughout the life cycle of a team.

Life Cycle of Teams

Teams are characterized by standard time frames during their lifespan (Fig. 27.3). Prior to the team's creation, there is a perceived need for such a team that may be termed the "drive" for team creation. Indeed without such a need, the driving force for team assembly is notably less focused leading to a team that is diffuse in targeting and broad in scope. Lack of focus may compromise training and utilization leading to a team that is ill equipped to address the mission at hand. Once assembled, critical incident response teams "strive" to achieve a high level of performance that is task oriented and mission specific. It would not be appropriate for a SWAT team to prepare for firefighting, for example. Once assembled, trained, and deployed, teams "thrive" and refine their membership, skills, and capabilities. It is during this period that teams refine their mission. Some teams expand and others contract depending on local need and capability. Having done so, teams achieve a level of competency and may be characterized as having "arrived," demonstrating organization that reflects a competency-based hierarchy. After a period of time

Fig. 27.3 Team life cycle

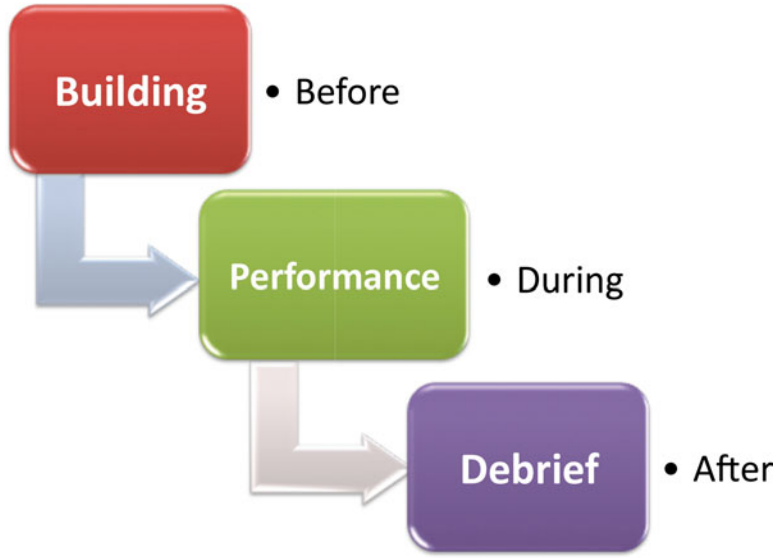

Fig. 27.4 Stepped plan for team management

and without a new drive, teams may atrophy, losing the crispness of their skills sets and decreasing the rate of new skill acquisition. Such events may reflect the aging of team members, lack of utilization as the original drive has been eliminated or decayed, or leadership failure as well as a host of other influences including deficient funding for training. Team salvage hinges on entering a phase of "revival," relying on a new entry into the life cycle demonstrated in Fig. 27.3. Such driving forces often represent changes in the threat matrix or dynamic, changing environmental demographics, shifts in leadership priorities, or new team leadership or membership. One way to help support team dynamics is to evolve a stepwise plan for team management that addresses team building, performance, and debriefing (Fig. 27.4).

Team Building (Before)

Team building is both an internal and external process. The internal aspect involves progressive team training for different scenarios so that team members become facile at their tasks and are prepared to address the spectrum of challenges that they might face. Besides supporting the development of transactive memory, teams also develop an esprit de corps, especially in teams where each team member is directly responsible for the lives of the other members [20]. Accordingly, a sense of personal responsibility characterizes well-functioning teams. These intense relationships generally do not occur within disparate teams. Accordingly, specialty teams should prepare to interface and work with other teams, rendering team building an external process as well. Regional exercises that bring disparate teams together and drive EMON evolution followed by a performance review support this goal. Citywide mock disaster exercises are prime examples of this kind of team building. Since details are easily lost, trained observers as well as digital recording of events for post hoc critique might identify opportunities for performance improvement.

Team Performance (During)

Military actions frequently benefit from real-time digital oversight via satellite imagery, drone-based feed, as well as fixed or mobile digital feed. Recording actions, environmental elements, verbal cues and directives, and reactions and integrating each of those elements with pre-action and intra-action intelligence is one method of evaluating team and commander performance. Other methods clearly exist and the method selected should match the available resources. Nonmilitary critical incidents generally are bereft of such imaging and integrated data. Nonetheless, the rapid rise of dashboard cameras, bystander video imaging, as well as the increasingly ubiquitous traffic cameras may allow for a piecemeal approach to critical incident team performance reconstruction especially in urban locales where such surveillance is more plentiful. Additionally, critical incident managers can team with media outlets to obtain data such as wide-angle helicopter footage or multi-angle imaging. Such relationships also allow managers to restrict the flow of information back to the general public, where perpetrators of a crime might access it. Such was the case during hostage negotiations that occurred in January 2013. In this widely televised negotiation of the release of a 5-year-old boy from a bunker, the FBI Hostage Rescue Team used information to build a model bunker. The model was then analyzed and accessed multiple times via various techniques in full scale to best plan the breach. All of this was done nearly on scene and unbeknownst to the kidnapper, leading to successful rescue of the victim several days later. Suburban and rural events may be enhanced by responder helmet or vest cameras as well as other novel methods of image capture including mobile devices such as tablet computers. As such, planning for intra-incident team performance evaluation tools should be included in resource management planning.

Team Debrief (After)

Post hoc review is a cornerstone of performance improvement and quality assessment. Improvements in individual performance, team coordination, information flow, communication resources, resource management, command decision-making, initiative maintenance, as well as interagency coordination [21]. Obtaining perspectives from individual team members, the on-scene team leader, and the command post is ideal as it provides a broader perspective on performance. It is essential that reviews are nonjudgmental. This encourages accurate and honest evaluation and insight into process improvement. Additionally, a key element in maintaining a longitudinal perspective is accurate documentation of elements that are beneficial, those that are merely acceptable and equally important, and those that hinder plan execution. Such a log is also useful in identifying evidence-based interventions targeted to improve focused performance areas. This information will be important to administrators who will be funding the interventions. More importantly, such a log creates a matrix of capabilities that have been developed. Clear identification of the review process leader encourages ownership of the review, improving utility of the process as well as operator development. Frequently, more intensive training follows in the wake of after-action analysis. Of course, ensuring sufficient time for training is an element that should be managed under team building and resource management, but unique needs for focused training may arise.

The above process is even more important when the performances issue embraces interagency coordination and dynamics. Such improvements may require ironing out new relationships—in particular—command architecture as noted above. Regardless, changes should be recorded and may be codified into a standard operating procedure (SOP) or a memorandum of understanding (MOU). Regardless of which elements need to be improved from a process improvement standpoint, human elements that impact individual responder performance must be accounted for and actively managed [4].

Stressors to Be Managed (Fig. 27.5)

Health

Health assessment and maintenance are important in keeping team members on the job and capable of performing their duties. Each agency should have screening health evaluations of new hires. Oftentimes, the ongoing health maintenance is

Fig. 27.5 Stressors

less stringent [13, 14]. It is unclear if more intense health recertification would translate into outcome benefit, but consideration of regular maintenance for critical incident response teams may be relevant. There are few such teams with embedded physicians, but they might enjoy enhanced health maintenance compared to teams without physician teammates. Of note, certain health conditions preclude participation on a critical incident response team including, but not limited to: active coronary artery disease, seizures, diabetes, poorly controlled asthma, and psychiatric illness [22]. Health maintenance is increasingly important as team members become older, especially in civilian domains where critical incident response team members are likely dually tasked with primary patrol, canine, or detective duties. Such duties are generally less physically demanding than the responsibilities of the activated critical response team, potentially impeding fitness maintenance and enhancement.

Fitness

Fitness differs from health in that it is the measure of physical capability rather than the overall well-being of the body systems. As mentioned previously, the Cooper Institute Fitness Assessment is the most commonly used measure of civilian police fitness. Its application to critical incident teams is limited in that it overlooks the unique idiosyncrasies of these teams such as the additional weight of body armor, medical equipment, firearms, ammunition, and other tools including communication, entry, and surveillance gear that must be transported over uneven surfaces [23]. Just as important is the impact of the extreme stress associated with these situations on the ability to perform physical tasks. This cannot be underestimated. Maintaining a high level of fitness helps support the ability to perform well and recover after burst energy expenditure and enables a more stable shooting platform as needed. Indeed, fitness may be utilized as part of an agglomerated approach to member selection and maintenance. Such a paradigm has been crafted using iterative aerobic and strength assessment sequences both with and without duty gear and job-relevant task assessments. Such assessments have been demonstrated to correlate well with job performance for a regional SWAT team in the USA. Fitness may be significantly impacted by diverse elements including sleep deprivation.

Sleep Deprivation and Fatigue

No condition may be more insidious than cumulative sleep deprivation. Once acquired, the effects remain even after obtaining an appropriate amount of sleep thereafter. A plethora of untoward effects accrue from sleep deprivation including, but not limited to:

1. Inability to focus or concentrate
2. Micro sleep events
3. Lack of impulse control
4. Anger
5. Depression
6. Compromised motor skills
7. Reduced tolerance and ineffective coping skills
8. Cardiovascular disease
9. Weight gain and reduced endurance
10. Impaired judgment

As a result, high-risk occupations such as airline pilots and truck drivers have established safety limits for wakeful hours on the job. Even medical trainees must work within an hour-limited paradigm. Sleep deprivation has been linked with disruptive physician behavior as well as burnout and disordered personal relationships [24, 25]. There is no reason to believe that sleep deprivation would not have similar effects on critical incident response personnel as well [26]. Therefore, it is reasonable to establish a sleep deprivation awareness program as well as embedding the notion that sleep deprivation may render one unfit to serve on a critical incident response team if it is identified [27]. The commander of the team must craft and enforce a surveillance program to ensure safe and effective team performance. It is possible that team medics or physicians might strengthen the awareness of sleep deprivation and help to police the team from such problems. In particular, lengthy operations that occur without the benefit of mutual aid from neighboring teams run a high risk of creating sleep deprivation and fatigue in the deployed members of a single team. Therefore, resource management is essential in ensuring that there are appropriate substitution plans to mitigate against sleep deprivation and fatigue.

Home and Family

This domain is perhaps the most difficult to manage as personal issues escape the control of resource management. Additionally, stressors in personal life are oftentimes intimately related to factors such as fatigue and time management. The impact of family illness, family discord, as well as financial stressors cannot be overstated as they may have broad effects including sleep deprivation, loss of focus and concentration, diminished tolerance, and frayed temper control and anger. It has been suggested that these factors are associated with diminished performance and impaired interpersonal relations, particularly when several stressors are found in combination. Quite often home stressors lead to maladaptive solutions including alcohol and illicit substance misuse and abuse.

Alcohol, Illicit Substances, and Mental Health

Substance abuse is a well-documented problem throughout the membership of teams faced with fluid and high-stress scenarios, as well as individuals faced with the ravages of dysfunctional dynamics including poverty, domestic violence, interpersonal violence, and drug-related culture and behavior. Depression and anxiety coexist and thrive in the daily reinforcement of failed social (police, social service, child welfare, etc.) interventions. As a result, law enforcement personnel are particularly vulnerable to these influences, as are social workers, EMS providers, and individuals working in the emergency department. Education is a useful step to combat this process but must be coupled with surveillance and intervention elements to prevent alcohol or illicit substance abuse. Multiple screening tools are available but often perform less well than the candid observations of well-meaning team members [12]. A robust employee assistance program is invaluable in this regard, as is the iterative feedback from invested team leadership and membership.

Stress and the Pyramid of Complexity

One method of understanding stress is to imagine it as a pyramid. In this regard, the critical incident itself forms the base, upon which all other stressors will rest. The next tier that directly relates to the incident is the team, the essential elements of which have been covered above. The third tier is the community in which the team finds itself and is sharply influenced by the community's attitudes toward team members and their mission. A well-regarded and well-funded team will be less stressed by its interaction with the community compared to one in which the teams' presence is regarded as intrusive, unwanted, and unsupported. The culture of the police environment is tied to both internal and external forces including hierarchy, monetary investments, commitment to education, and support in terms of hours trained and resources allocated. The local government structure support of the agency is also linked to its success and regard. The critical incident team also participates in image building in that interactions with community members, local leaders, and media outlets shape the way that the team is perceived. Political issues top the pyramid and serve as the "sharp, pointy end" of the stress climate. Even when everything goes as well as one could hope, the political spin can substantially alter how the process, conduct, and outcome of a particular critical incident are viewed. It is essential that the politics be kept at arm's length from the team and their mission. Political issues are optimally handled by the upper reaches of administration instead of the deployed team or its commander. The commander is a key figure in negotiating pre-incident relationships with other agencies.

Interagency Collaboration

The success of local critical response teams is in part dependent on healthy relationships with state, regional, and federal agencies. Fusion centers provide key information to a variety of agencies throughout the country in an effort to streamline the response to violent extremism and reduce its occurrence. It is not uncommon to need to interact with the National Guard, Federal Bureau of Investigation, Alcohol Tobacco and Firearms, Department of Homeland Security, US Marshalls, and others even within a low-activity locale. Therefore, roles, responsibilities, and communication lanes are ideally established by protocol prior to a critical incident or even a joint task force undertaking. Doing so reduces the likelihood of error, injury, and even loss of life. Members of the aforementioned agencies are trained operators. As such, they share many similarities with the members of a local team. Bystanders, on the other hand, in general do not.

Bystanders

The untrained bystander plays an increasingly prominent role in critical incident response [28]. However, these spontaneous responders fall outside of the paradigm of crew resource management and team dynamics as they do not participate in any aspect thereof. The frequency and impact of bystander efforts are underscored by the recent Boston Marathon Bombing of 2013. Initial rescue efforts were undertaken by bystanders in advance of trained rescue crews [29]. The Centers for Disease Control and Federal Emergency Management Agency have recognized the impact and efforts of bystanders in critical incidents. Accordingly, these agencies are in the process of developing bystander training tools to better prepare for critical incident participation in advance of trained team arrival, especially where team arrival will be delayed or nearly impossible due to local geography or weather concerns (i.e., rural sites, mountain locales, etc.). Therefore, trained operators of multiple specialties will need to determine how best to interact with engaged bystanders to optimize bystander assistance. Specific training may be required to best use this resource, while the nation struggles to establish a culture of competence in the setting of critical incident response.

Emergency Medical Services/Tactical EMS

Recent changes in the thinking behind how best to position and utilize trained medics and physicians who are embedded in critical incident response teams have moved medical providers closer to the hot zone or inner perimeter. Previously, providers were most commonly positioned outside of the threat zones. This ensured their safety and separated team members based on the type and degree of their training. Recently, medical providers have been integrated into critical response teams where they largely remained unarmed [30]. In the wake of the well-publicized active shooter events in schools, malls, and other locales, bringing a trained provider to an injured individual who cannot be extricated may be lifesaving. The tenets of Tactical Combat Casualty Care (TCCC) provide guidance on what kinds of lifesaving activities are appropriate when under fire, as well as when out of the line of fire (Table 27.1) [30]. It is clear that to provide medical care in high-stress and low-resource settings, the provider must be a valued team member as their life is in the hands of the operators that escort the provider to an injured team member, victim, or suspect. A detailed exploration of these issues may be found elsewhere, as it is outside of the scope of this chapter [31–33]. Nonetheless, like bystanders,

Table 27.1 Tactical combat casualty care phases

Phase	Interventions
Care under fire	Threat elimination, tourniquet, temporary hemorrhage control, airway intervention general deferred until tactical field care
Tactical field care	Airway control, hemorrhage control, fluid resuscitation including intraosseous line insertion
Combat casualty evacuation care	Tube thoracostomy, continue fluid resuscitation, NO wound repair, oxygen administration (when available)

Adapted from [30]

teams must develop specific methods of interacting with, and embracing, medical support that follows them into dangerous territory to preserve life.

Conclusions

Team dynamics are both complex and straightforward. Scientific principles allow one to understand the complex interplay of forces that may enhance or degrade crew resource management. Dedicated efforts at team building, performance review, and performance improvement serve as the basis of enhancing team dynamics. However, a skillful leader who is imbued with command and control is required to craft a culture of safety and competence. Careful planning for contingencies and difficult scenarios, as well as interaction with other agencies—including untrained bystanders—helps underpin team success. However, even the most careful planning will fail if it rests upon a dysfunctional team. Therefore, improving team capabilities, competencies, fitness, health, and interpersonal dynamics is the linchpin that holds all components of the critical incident team together.

Key Points

- Understanding critical incident response dynamics and logistics is enabled by a scientific approach to each element.
- Command, control, and communication are key elements that are required for successful critical incident leadership.
- An iterative process evaluating team dynamics and logistics before, during, and after incident response is essential in supporting continued team performance improvement.
- Individual team member management dovetails with team performance.
- Interagency coordination should be specifically planned, tested, and critiqued to optimize performance and help ensure a successful resolution upon team deployment.

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Terrorism and Urban Trauma

28

Steven R. Allen, Kevin Glenn, Jonathan Mulhern, and Lewis J. Kaplan

Introduction

The last few decades have witnessed a fundamental shift in how the public, law enforcement, federal agencies, and the military perceive terrorism and urban trauma. Previously, terrorism and urban trauma were considered as distinct entities. Terrorism in particular was an event that primarily occurred outside of North America, most notably affecting certain countries in the European Union, the Middle East, and areas of South America plagued by the illegal drug trade. The historic events of 9/11 revamped those perceptions and painted terrorism and urban trauma onto the same canvas. While urban trauma remains largely focused in large cities with high population density in zones with low socioeconomics and high criminal activity, the culture of urban trauma has crafted its own norm impacting multiple forms of media as well as behavioral expectation [1].

Terrorism on the other hand has exploded and encompasses a vast array of forms [2]. Domestic terrorism including the well-publicized school, mall and movie theater shootings, as well as gang violence has come to weld terrorism and urban trauma together [3–6]. Other forms of terrorism in this modern era remain distinct including cyberterrorism, identity theft, and random interpersonal violence that follows a dictated form such as the recent spate of "knockouts" that have occurred on public transportation and urban sidewalks where bystanders have been targeted for violent assaults leading to unconsciousness [7]. Together, terrorism and urban trauma have the potential to shape a culture of fear, a goal that underpins terrorist activities in all forms.

Forms of Terrorism and Urban Trauma

Mass casualty scenarios often typify thinking about terrorist events whether domestic or international. However, most mass casualty events that relate to terrorist activity tend to result in large numbers of dead individuals with far fewer individuals with serious injury requiring inpatient hospital care but large numbers who require emergency department care; 9/11 serves as a prime example. Natural disasters in comparison, including typhoons and earthquakes, have a more balanced injury profile that has a tendency to overwhelm the existing capacity of medical care facilities as well as logistical difficulties in bringing additional capability to the site of disaster. Examples include the natural disasters that struck Haiti [8, 9] as well as the southern USA during hurricane Irene [10]. Individual terror attacks, including those derived from autonomous "cells" [6], are characterized by decreasing mortality but increasing need for care that radiates outward from the epicenter of the attack; numerous such examples are found throughout the history of Israel [11].

Regardless of the precise nature of a terrorist attack, mass panic and civil and financial disruption are other terror goals that may ensue and compound the loss of life [12]. Such

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Fig. 28.1 Trauma/terror cycle

events provide fertile ground for a culture of fear that is initially characterized by heightened awareness that is then followed by a gradual return to normalcy—a cycle that inadvertently readies the system for the next event (Fig. 28.1) [2]. The loss of vigilance provides an area of weakness that may be once again exploited to reinitiate the cycle. Most urban trauma does not aim to create unrest, but feeds into a similar cycle nonetheless. Accordingly, both medical and law enforcement domains have evolved and adapted to respond to preserve life, limit damage, and maintain or restore peace. The evolution of medical and law enforcement responses is driven in part by the kinds of injuries that individuals and groups may sustain.

Injuries and Injury Patterns

While urban trauma is commonly typified by penetrating interpersonal trauma that includes gunshots and stabbings, blunt interpersonal violence follows closely behind in frequency in the USA. Nonetheless, most urban trauma centers in the USA and Canada evaluate and care for more patients who are bluntly injured compared to those with penetrating trauma as a result of their regional resource status leading victims of falls and motor vehicle crashes to be transported from the scene or after stabilization at a less well-equipped medical facility.

Unlike urban trauma, terrorism often leads to both penetrating and blunt injury in the same patient [13]. This circumstance derives from the common occurrence of explosive devices such as improvised explosive devices (IEDs), suicide vests packed with explosives such as C4 (cyclotrimethylenetrinitramine) or Semtex (RDX [research department explosive]), an explosive nitroamine, and PETN (pentaerythritol tetranitrate) coupled with intentionally placed shrapnel such as ball bearings, screws, nuts, bolts, and the like, as well as secondary explosions from intentionally placed and delayed explosive devices, vehicles, fuel lines, or fuel depots. Such explosives lead to penetrating injury within the blast zone and blast effect within the blast radius; individuals may be thrown into stationary objects or mobile objects may be explosively moved into individuals [13].

Blast effect is a concussive injury derived from blast pressure measured in pounds per square inch (psi) during the rapid overpressure phase of the explosion [13–15]. For example, an overpressure of 1 psi leads to a maximum wind speed of 38 mph, while an overpressure of 10 psi creates wind up to 294 mph leading to severe damage to concrete structures and death in the majority of individuals exposed to the overpressure wave [16]. While military organizations are well acquainted with such injuries, civilian law enforcement and EMS may benefit from specific preparation including focused education, training, and resource management (see Chap. 27, Critical Incident Team Dynamics and Logistics).

No list of terror-related injuries is complete without specific mention of nuclear, biologic, and chemical (NBC) injury. Of the three, the first and last appear more readily realized by terrorist organizations due to the seemingly more limited availability of biologic terror agents such as weaponized anthrax or small pox in comparison to nerve agents or radioactive waste to manufacture a "dirty bomb." The essential feature of NBC terrorism is that its events may be difficult to initially detect (other than a bomb explosion) and result in significantly worse effects due to the delayed reaction of responders who may not be adequately prepared for or protected from such threats [17, 18]. These injuries are discussed further in Chaps. 31 and 32. Additionally, such an event has the unfortunate by-product of creating fear of another such attack, leading to the notion that there is no safe refuge, perpetuating a culture of fear—a prime goal of terrorism.

Nonetheless, in the event of an NBC terrorist attack, the availability of appropriate personal protective gear is critical to protect first responders who arrive to evacuate and care for the victims of the incident [17]. Microbe biohazard protection is provided by the appropriate biohazard gear (biohazard level I–IV suits), while chemical and biologic protection is provided by gear including the military mission-oriented protective posture suits (MOPP suits 0–4) [19]. The availability of upper level gear may be limited outside of special facilities, and high-level suits are not commonly available even at major medical facilities, including regional resource trauma centers. Accordingly, a close working relationship with local military resources is essential in bringing suitably trained and equipped individuals to an appropriate location. Little, if any, nuclear radiation protective gear is readily available outside of specialized agencies and their designated protective details such as those at the Lawrence Livermore National Laboratory (https://www.llnl.gov) and investigative and clean-up crews from the Nuclear Regulatory Commission (www.nrc.gov) and the National Nuclear Security Administration (www.nnsa.doe.gov).

Paradigm Shifts in Terrorism

The terror attack on US soil on 9/11 marked a major change in US policy as terror firmly landed in North America, initiating the "Global War on Terror" [20]. Instead of supplanting a country's governmental infrastructure, or unseating its political leadership to establish new rule, or driving out an invading force, terrorism shifted to coordinated attacks performed by small teams of terrorists. While structures were destroyed, the primary impact was on people and their view of the government. The small units, termed "cells," operate both as part of a coordinated structure and independently [6]. Some may be in place for a short period of time prior to their specified activity, while others may remain dormant for long periods of time and are dubbed "sleeper cells" [6]. Thus, terrorist activities became personally focused instead of government or country focused.

The rise of social media and the widespread use of the Internet as a communication tool as well as an enabler of daily activity have afforded multiple opportunities for cyberterrorism [21]. Such activities span network disruption and identity theft and lead to organization member recruitment and have resulted in an expansive need for law enforcement capabilities [21]. Even small police departments support electronic expertise in crime solving and as such complement cyber policing that is performed by federal agencies such as the National Security Agency, the Federal Bureau of Investigation, and international agencies that include the Central Intelligence Agency [21].

Domestic terror events such as the Texas bell tower shootings that occurred in 1966 have resulted in the formation of Special Weapons and Tactics (SWAT) teams, as championed and refined by the LA County Sheriffs' and Police Departments, and have flourished. In fact, since the 1970s, SWAT teams have increased by 80 % encompassing urban and suburban terror events spanning (but not limited to) barricaded hostage/suspect, riots, gang warfare, dignitary protection, and high-risk warrant service [22]. Driving the development, training, and outfitting of local SWAT teams is the need to respond to the changing demographic and advanced, high-powered equipment of perpetrators of violent crimes. Suspects and organized criminal elements have ready access to body armor and high-performance weapons as a result of military surplus obtained both legally and illegally. Additionally, increasing numbers of perpetrators of violent crime may have served as members of the armed forces and received specific weapon and tactical training [23]. Therefore, local police departments need to be able to respond to a host of different events forcing a metamorphosis from community-based policing to a threat matrix-based response. The transition has often been termed the "militarization" of local police forces and is typified by the inclusion of military relevant firearms, body armor, communications gear, training tactics, sound and light diversionary devices [24], and up-armored vehicles such as the Lenco BearCat, a mission-specific personnel carrier with both high-powered firearm and explosive device resistance. Some civilian departments in cities with frequent SWAT activations have begun investing in mine-resistant armored personnel (MRAP) carriers identical to those in service in Iraq and Afghanistan.

Similarly, instead of standard community policing where apprehending criminals constitutes approximately 10 % of total police work, departments are now devoting increased time and resources to elements that include active shooter scenario training [24]. Furthermore, and in a fashion parallel to that of the military, police officers are increasingly trained in self- and buddy aid using concepts and tactics borrowed from the Tactical Combat Casualty Care (TCCC) approach advocated initially by the Naval Special Warfare Command [25]. Recognizing that the patrol officer is likely to be the first responder to urban trauma or terror acts, this officer's capabilities need to be enhanced and reinforced to increase the likely survival of the officer and those whose lives the officer has sworn to protect [25].

Such needs have also driven increased interagency collaboration with other law enforcement agencies including but not limited to state police; US marshals; Alcohol, Tobacco, Firearms; Drug Enforcement Agency; FBI; US Secret Service; and the National Guard as needed [26]. Since communication is key to such activities, the USA has developed fusion centers under the aegis of the Department of Homeland Security that are designed to funnel key and actionable intelligence to appropriate agencies within a specified territorial domain designed to disrupt potential or validated terrorist threats. Integrated domains include state, local, tribal and territorial, as well as private sector partners (www.dhs.gov/state-and-major-urban-area-fusion-centers) [27]. Such communication is key to protecting and preserving national security by establishing and improving an information-sharing environment to help counter violent extremism.

Changes in Emergency Medical Systems Structure

Medical care as part of an organized trauma system began in the 1970s and continues to be refined today. In general, urban emergency medical services combine ground and rotary wing air ambulance transport into a working network that embraces support from both the local fire department and the local police department. Rural trauma systems may fold in aid from other agencies including the US National Park

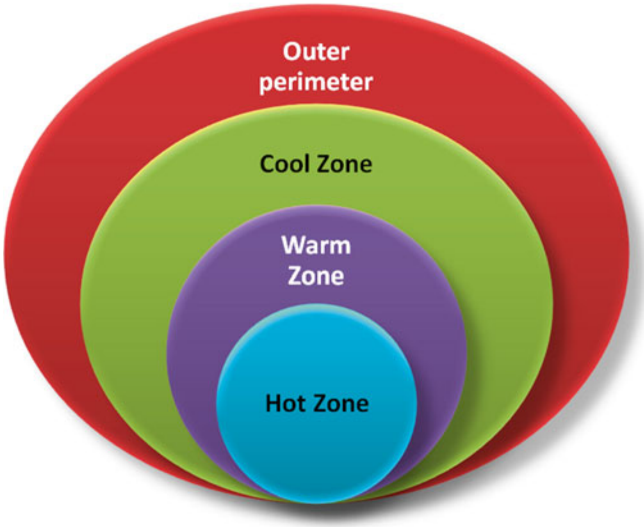

Fig. 28.2 Zone schematic

Service (www.nps.gov) and in Canada, the Royal Canadian Mounted Police (www.rcmp-grc.gc.ca). Of necessity, the EMS response to urban violence is reactive in nature rather than preemptive. Nonetheless, despite the close working relationship with local law enforcement, only few areas of crossover have blossomed that leverage the capabilities of EMS with law enforcement.

One such domain is Tactical EMS [28], a concept spawned in the military and in particular in special operations forces where one individual embraced both operator and medic roles, providing immediate and skilled life-sustaining emergency care to an injured combatant rather than needing to await evacuation to a higher echelon of care. While a superb concept, such an individual seems more difficult to task in the civilian domain where issues such as divided loyalty (which role at which time) as well as skills maintenance and certification (medic and police officer) are particularly problematic [28]. Instead, at least in US practice, the medic and police officer roles are generally shouldered by separate individuals. Previously, EMS care during a police action such as a SWAT team activation (callout) for a barricaded suspect/hostage would await threat elimination and scene clearance or extrication of a wounded individual out from the inner perimeter or "hot" zone (Fig. 28.2).

Based on the work of individuals such as Richard Carmona, MD [28], a former US Army medic and former surgeon general, medics embedded in US SWAT teams have flourished. Such medics train with the SWAT teams and are viewed as integral members, but are tasked with medical care, not room clearing and suspect apprehension. Given the tenor and pace of active shooter scenarios starting with the Columbine, CO, school shootings in 1999 and culminating with the Newtown, CT, school massacre in 2012 [4], even the US President, has provided vocal support to sending medics into the warm zone to effect rapid care of injured individuals [29].

Physician involvement in Tactical EMS (TEMS) is principally limited to providing medical command for the tactical team medics, rather than direct participation. Furthermore, the vast majority of physicians involved in TEMS in the USA are primarily trained in emergency medicine [28]; only a handful of surgeons participate in TEMS. The majority of emergency medicine physicians provide medical direction but do not deploy with the SWAT team. However, the majority of surgeons involved in TEMS do so as tactical team members, deploying with the team and providing on-scene medical care and medical command. Such physicians are equipped with nearly identical gear as the SWAT operators, trading firearms for medical equipment. Bearing the added weight of body armor, communications gear, and medical necessities can present a substantial physical challenge, leading to significant physical fitness requirements for the interested individual [30]. The ethics of placing a physician in such a role has been extensively explored [31].

An embedded physician parallels the military structure of some far-forward teams with on-scene physician support such as has been utilized by the US and the Israeli military. Moreover, once the physician integrates with a SWAT team, the opportunities for influencing care across the entire police department abound. Importantly, such influences may change medical preparedness for both urban violent injury and acts of terrorism. Such examples may include changing the medical kits that populate mobile police platforms to ones that include tourniquets, personal protective gear, and procoagulant dressings [25]. Implicit in such a change is that there is appropriate training to enable gear deployment and use in a safe and effective fashion. In many ways, members of the local community may have already done so in the form of "go bags" and immediate care gear that is secured in their personal vehicle.

Improved Community Preparedness

In many ways, civilians are moving toward embracing a culture of competence. Such mobility is spurred on by terror events such as those of the 2013 Boston Marathon bombing where community aid was key to preserving the lives of many of the injured. Community training and resource management enhances bystander willingness to participate in events where they may sustain injury while offering aid. Indeed, organizations such as the American Red Cross and the Canadian Red Cross have a host of training courses designed to improve an individual's ability to provide self- or buddy care. A readily downloadable app serves as an immediate guide for most major medical emergencies if instruction or immediate aid is unavailable including step-by-step instructions as needed. The US Federal Emergency

Management Agency in combination with the Centers for Disease Control is readying to launch a bystander emergency preparedness training course with the ability to have independent online and on-demand study as well as typical classroom didactics. Certainly, wilderness exploration and the related organizations have championed "Wilderness Medicine" courses that teach advanced aid skills [32]. The ready availability of tactical load-out bags, EMS bags, personal protective equipment, and hemorrhage control aids (including tourniquets and procoagulant dressings) enables the competent civilian bystander to be ready to render aid in an on-demand fashion be it at a motor vehicle crash, a drive-by shooting, or a terrorist attack [33]. In an extreme fashion, movements such as the so-called Doomsday Preppers may have enhanced medical gear including gas masks, providing both enhanced medical capabilities and increased protection from standard SWAT techniques that utilize chemical irritant gas to deny the suspect protected space.

Conclusions

Urban trauma and terrorism share a wide variety of overlapping issues that impact how law enforcement and EMS prepare for and respond to emergencies. The changing threat matrix has driven significant changes in policing from a community-based approach to a threat-based posture. Key events including the Global War on Terror, access to military grade weaponry and surplus gear, and global connectivity via the Internet and social media have revamped the landscape of both urban trauma and activity designed to thwart violent extremism. Interagency synergy hinges on communication and the timely distribution of actionable intelligence but at present still relegates most law enforcement and EMS activity to reacting to established events rather than being able to preempt events. Integration of medics and physicians into a TEMS approach may enhance outcomes for injured individuals. Community preparedness and bystander involvement are helping to shape a culture of competence, and both EMS and law enforcement will need to determine how best to effectively train, utilize, and interact with engaged bystanders during the response to urban trauma or terrorism.

Key Points

- Urban trauma and violent extremism share broad areas of overlap with regard to their impact on social structure and preparedness.
- Terrorism paradigms have shifted to small units that are difficult to preempt.
- Law enforcement benefits from including medically trained personnel into rapid response teams.
- EMS and law enforcement will need to proactively prepare to interact with trained bystanders in the near future.

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Tactical Emergency Medicine, Procedures, and Point-of-Care Evaluation in Austere Environments

29

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Introduction

Most physicians never experience the practice of medicine outside the hospital, emergency department (ED), or the office clinic setting. Some physicians will spend time on ground or rotary wing ambulances where capability is significantly limited over the broad scope of the ED and trauma bay. However, most modern ambulances and especially air ambulances have electrical power, EKG (electrocardiogram), and ventilator capability, as well as defibrillation, suction, and many other pieces of equipment that allows the well-trained emergency provider to complete an array of critical, lifesaving procedures. eFAST (extended focused assessment with sonography in trauma) available via a new generation of highly portable ultrasound machines is a cornerstone of trauma imaging evaluation by methods other than plain x-ray, computed tomography (CT), angiography, or magnetic resonance imaging (MRI).

Hospital-based clinicians are typically surprised by the varied procedures performed with equipment carried in a physician's backpack with a Special Weapons and Tactics (SWAT) team aided by the use of a portable ultrasound machine. Not only are many of the same procedures performed in the ED or trauma bay possible in the field, accurate diagnosis of potentially life threatening or life-threatening injuries such as pneumothorax, hemothorax, main stem bronchial intubation, head injury, and others is possible in the most remote locations. Although there is evidence to support a scoop and run approach for trauma patients in typical settings, these studies are not applied well to a situation where evacuation is unsafe such as a combat zone or impossible due to remoteness or inaccessibility of the setting [1–4]. In such cases, intubation and ventilation, placement of thoracostomy tubes, and other procedures are hours to days off and may have to be performed on site.

Austere and Tactical Environment Emergency Medicine

The austere and tactical emergency medicine environments are typically similar but not synonymous. One tends to assume that in most tactical situations, organized help is readily at hand and standing by. However, in some similarity to an austere setting, the tactical emergency physician may be deployed with a SWAT team seeking an active shooter in a modern office building of a large city and have no access for hours to equipment or gear other than what they carry on their back. While most SWAT team members carry gear in addition to their body armor and helmets, such as gas masks, they are not weighed down as much as a tactical physician who carries a large amount of medical equipment on his/her back (Fig. 29.1). Despite the encumbrance a large heavy bag provides, it is necessary for the tactical emergency physician to perform their job. In many cases, tactical physicians are armed only with side arms and do not carry long guns. They are tasked with protecting their patients who may be victims, SWAT team members, or even suspects, but are typically not the first to enter a building.

Physicians performing emergency care in a non-tactical, austere setting still benefit from a well-stocked equipment

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Fig. 29.1 A tactical emergency physician equipped with a medical pack, portable ultrasound machine, body armor, and weaponry

bag. Not wearing body armor, helmet, or other tactical gear saves weight and may allow the physician to carry additional medical supplies. As opposed to a tactical deployment, a physician providing care in the austere environment may be much further away from potential evacuation and medical help and be required to care for their patients not just for hours but days. Prolonged care without evacuation is most likely to happen in a remote expedition setting, and patients may have to be cared for through recovery and continuation of the expedition.

Equipment for the Tactical and Austere Environment

Although it is still unrealistic to carry a laboratory analyzer in the physician's bag, some point-of-care testing consisting of small analyzers using cartridges could be transported. Such tests typically evaluate cardiac-related processes such as troponin and beta-natriuretic peptide, but other additional testing such as electrolytes may also be available. For a physician traveling to an austere environment, such equipment may be desirable, especially if members of the group are older and/or have existing illnesses. Such portable blood analyzers are less likely to benefit the tactical physician on a deployment or rendition. Equipment recharging capability may be available by employing one of a host of over the counter solar recharging kits often capable of slowly charging batteries in portable devices. One piece of equipment that provides broad diagnostic imaging capability is found more and more frequently in tactical and austere settings [5–9]. As Fig. 29.1 shows, the portable ultrasound machine has its place in tactical medicine as well as in austere environments.

The remainder of the gear focuses on critical procedures and traumatic injury care. Since blunt trauma is always a risk, the equipment bag should include a cervical collar and splinting material, the latter of which could be of the inflatable variety. Almost like an athletic trainer, tape and bandages are important to have. In reality, one would bring much of the trauma bay if room allowed. Equipment trays take up too much space, but essential sterile pieces can be brought. Chest tubes, typically two, suture equipment, and a stapler are essential. Clotting material such as a lava rock product is imperative along with tactical tourniquets for hemorrhage control. Compression devices to occlude the abdominal aorta or ipsilateral common iliac artery may be lifesaving in cases of inguinal wounds where hemorrhage cannot be adequately controlled with local compression [10, 11].

Intubation equipment is likely to be limited to one handle and one or two blades as well as several endotracheal tubes. A cricothyrotomy kit is essential, as well as a bag valve mask apparatus. Suction is typically limited to a large syringe and rubber tube to suction the mouth and airway if absolutely needed.

Medications are essential, including intravenous fluids, but providers are unlikely to have more than one or two doses of any medicine, and carrying more than one or at most two liters of fluid may significantly weigh down the medical bag. Antibiotics are more critical for longer expeditions, and a large portion of the pack may have to be devoted to a variety of antibiotics, antiparasitics, and antifungals, depending on the destination. Antibiotics carried would include broad spectrum drugs in states not requiring refrigeration. Coverage would typically include skin, bowel pathogens, and urinary tract and pulmonary tract pathogens. Realistically, a handful of antibiotics such as a third-generation cephalosporin, a broad spectrum fluoroquinolone, and a lincosamide can be used to cover a broad swatch of bacterial illnesses encountered. Tactical physicians will have few antibiotics, mostly in the case of open fractures and deep penetrating wounds providing coverage for skin and bowel pathogens. These would be given when immediate evacuation is impossible such as in a relatively remote area or when the area may remain unsecured for a prolonged period of time, limiting emergency medical services (EMS) or aircraft access. Essential medications include paralytics and sedatives along with standard advanced cardiac life support (ACLS) medications such as epinephrine, atropine, and others. Pain medications are likely to be required with penetrating wounds and blast injuries as well as blunt trauma.

Procedures

Procedures such as intubation, thoracostomy tube placement, and peripheral and central line placement are performed in much the same way one would in a trauma bay or ICU setting. Intraosseous (IO) access can be a rapid, albeit a very temporizing, measure to obtain access. The inherent vulnerability of an IO line to unknown dislodgement is exaggerated in the field where the patient may be moved rapidly and roughly due to terrain, weather, or even gunfire. However, no backup is likely to be available and, other than portable ultrasound, no follow-up imaging to confirm either chest or endotracheal tube placement. Pain control may be required in either tactical settings or austere environments; in either case, capabilities to provide long-term pain management are likely to be limited. In some cases, nerve blocks may be ideal in dealing with significant extremity injury especially in settings when evacuation is likely to be delayed.

Procedures are likely to be performed in less than satisfactory conditions and improvisation may be required. An example is a resuscitation during a SWAT team deployment in Columbia County, Georgia, in 2006. A SWAT team containing two tactical physicians entered a house of an armed barricaded suspect. Upon entry, the suspect produced a handgun and shot himself in the left anterior chest. The suspect was in impending respiratory arrest but continued to struggle and resist assessment and treatment within the confines of his small bedroom. A peripheral IV was established and the patient was given etomidate and succinylcholine. However, during the struggle the IV infiltrated and he did not receive the medications. Additional saline for dilution of the succinylcholine was unavailable, and the physicians mixed the last dose of etomidate with the powdered succinylcholine. The medication was injected directly into the suspected femoral vein due to the failure of another IV line. The patient was bagged and rapidly intubated. Auscultation, however, revealed no breath sounds in the left chest even after endotracheal tube withdrawal. The patient's chest was needled and physicians proceeded to place a thoracostomy tube. The equipment bag had been overturned and bedsheets mixed with the equipment. Additionally, electrical power was cut during the raid, and procedures were performed under illumination of SWAT team weapon's lights. Clamps for blunt dissection to the ribs and penetration into the thoracic cavity could not be located. After scalpel incision, the physician placing the chest tube was forced to bluntly dissect with his thumb through the soft tissue and was able to penetrate through the chest wall, releasing a large amount of air. The chest tube was inserted but no needle drivers could be located to suture the chest tube in place. A utility tool borrowed from a SWAT team member was used to complete suturing. A latex glove with a finger cut distally was taped at the end of the tube to act as a Heimlich valve. A large quantity of chlorhexidine was available and used extensively during the procedure. The patient was later airlifted and survived to discharge. He required no surgical intervention during his stay in the hospital.

This example serves to highlight the need for improvisation in tactical and remote conditions. Such improvisation is especially critical in combat zones where patients may have to be treated rapidly and moved to a more secure location.

Assessment and Testing

Performing point-of-care laboratory testing during prolonged expeditions may be possible in some cases. For most, the physical examination is the major assessment tool. Even more than in the hospital environment, the tactical physician is likely to have a firsthand understanding of the limitations of the physical examination, the accuracy of which is being questioned more than ever [12, 13]. Patients may be severely injured and unconscious or be in loud environments or unsecured locations. It may be necessary to maintain a covert position and the use of lighting at night might be too risky. The portable ultrasound machine is an ideal all-purpose diagnostic tool and an extension of the physical exam. The tactical physician will typically use eFAST applications to search for free fluid, cardiac injury, pneumothorax, and signs of head or vascular injury. In the austere environment of an expedition, the physician may encounter general medical complaints and be required to image the gallbladder, bowel, and pelvis, among others. The tactical physician is not immune to such requirements either. During a large-scale drug raid in 2005, a tactical physician performed not only several trauma-related examinations but a lung examination diagnosing pulmonary edema in one bystander, as well as an abdominal ultrasound examination revealing a large left adnexal mass that later turned out to be an ectopic pregnancy in another bystander. These assessments were necessitated due to the remote rural location of the raid and the large curtained off area that took time to secure.

Conclusions

Tactical and austere medicine both provide a wide variety of potentially critical ill patient scenarios. The critical difference is the need for a physician to be prepared for combat in the former. Many of the same procedures performed in a modern trauma bay or ED may be performed at the patient's side in combat or remote areas. With limited backup and evacuation options, such procedures may be lifesaving. Improvisation is critical, and the use of the only imaging technology available from a pocket or backpack, the portable ultrasound unit, greatly enhances the providers' capabilities and accuracy. With proper training and preparedness, the tactical and austere medicine provider will serve a critical role in patient care and in turn be rewarded with a unique work experience few participate in.

Key Points

- Most procedures available in the trauma bay may be required in the field.
- Prepare with intubation and resuscitation medications and fluid.
- Few diagnostic tests are available.
- Portable ultrasound greatly enhances the providers' diagnostic and therapeutic capabilities.
- Improvisation and use of available tools can help overcome limitations in the field.

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30 Trauma in Austere Environments: Cold Injuries and Hypothermia

Mansoor Ali Khan and Heidi L. Frankel

Introduction

The importance of cold injury has been well known for more than two millennia. One of the earliest accounts of cold weather injury documented in literature stems from the time of Hippocrates where he wrote: "in some instances blisters arise as if from burning with fire, and they do not suffer from any of those unpleasant symptoms until they become heated" [1].

Hannibal's invasion of northern Italy also demonstrated the severe effects of the cold climate. He led 38,000 infantry personnel across the Alps, of whom only 19,000 survived. The majority succumbed to cold and altitude [2].

Napoleon, in 1812, launched a campaign against the Tsar of Russia, to consolidate his stronghold in Europe. His initial army numbered more than 612,000 men from various nationalities. However, by the time the conflict was over and the harsh Russian winter had taken its toll, the final number was approximately 50,000 men [3].

The First World War introduced the discrete pathophysiological process known as trench foot as a result of cold immersion. The Second World War received the most documented cases of cold weather injury. The Germans fighting on the Russian front sustained more than 250,000 cold-related injuries in just one winter. The Russians, whilst attacking the Finnish army, in the Battle of Suomussalmi lost 27,500, killed or frozen to death [2]. The icy conditions prevalent in Korea during the war there in the early 1950s also resulted in large numbers of casualties due to cold injury.

Despite improvements in equipment and clothing, cold injury continues to be a problem in wartime. In the Falklands conflict, when mean air temperature ranged from 10 °C by day to –4 °C at night [4], at least 20 % of evacuated British casualties suffered from cold weather injury [4]. In a study published by the Israeli Defence Forces, they demonstrated that over a 10-year period, there were 242 cases of cold weather injuries. Peripheral cold weather injuries accounted for 55 % of cases, and hypothermia accounted for the remaining 45 % [5].

Classification

Cold injury may be conveniently grouped into systemic injury (hypothermia), freezing cold injury (frostbite) and nonfreezing cold injury. Although these three patterns of injury are distinct, they may coexist within the same casualty to varying degrees and alongside various traumatic injuries; therefore, a global approach to the management of cold injury is essential.

Hypothermia

Pathophysiology of Hypothermia

Hypothermia is characteristically defined as a core body temperature of 35 °C or less. This can be further divided into two categories:

- Mild to moderate hypothermia (30–35 °C) presents with symptoms including shivering, confusion/disorientation, drowsiness, exhaustion, poor coordination, slurred speech and numbness.
- Severe hypothermia (<30 °C) presents with similar symptoms as those described for mild and moderate hypothermia and is often associated with cardiac dysrhythmias.

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In an otherwise fit and healthy subject, hypothermia occurs when the drop in temperature is cold enough to overcome the body's ability to appropriately compensate with thermoregulation. This characteristically occurs with prolonged exposure to the cold environment; however, it is important to note that hypothermia can occur in any setting. Secondary hypothermia occurs in patients who are susceptible due to underlying medical conditions that interfere with thermoregulatory processes (such as exsanguinating haemorrhage and high-volume resuscitation).

There are four factors that are implicated in causing hypothermia:

- Impedance of circulation
- Increased loss of heat (convection/conduction/radiation/evaporation)
- Decreased thermogenesis
- Impairment of thermoregulation

Impedance of circulation can occur for a variety of reasons and, usually, is due to underlying medical conditions. Heart failure can lead to inadequate circulation, thereby increasing an individual's potential to become hypothermic. In theory, peripheral vascular disease can lead to hypothermia; however, these patients are more likely to develop peripheral freezing and nonfreezing cold injuries.

Convection is best described as the transfer of heat across an object, caused by either gas or liquid, with the rate of heat loss dependent on the density and velocity of the fluid.

Conduction refers to the transfer of heat between two objects that are in direct contact, with the most obvious example being an individual immersed in water. The temperature differential and also the composition and subsequent thermal conductivity of the other object are important. Granite has four times the conductivity of water, a point to be noted if an elderly patient has been found collapsed on a tile floor and has been there for a number of hours.

Radiation of heat occurs in all environments and is related to the difference between skin and surrounding environmental temperature. Important factors in heat loss by radiation are the surface area and the temperature gradient.

Evaporation is heat loss that results from converting water from a liquid form to gas such as from respiration and perspiration. This can also have a knock on effect; profound evaporation can lead to subsequent volume loss with decreased circulating blood volume, further causing hypothermia.

Systemic Manifestations of Hypothermia

Hypothermic patients display bradycardia and hypotension with elevated systemic vascular resistance and various conduction abnormalities that manifest as atrial or ventricular fibrillation or asystole. The electrocardiogram may demonstrate a repolarisation abnormality known as the Osborne J wave (Fig. 30.1).

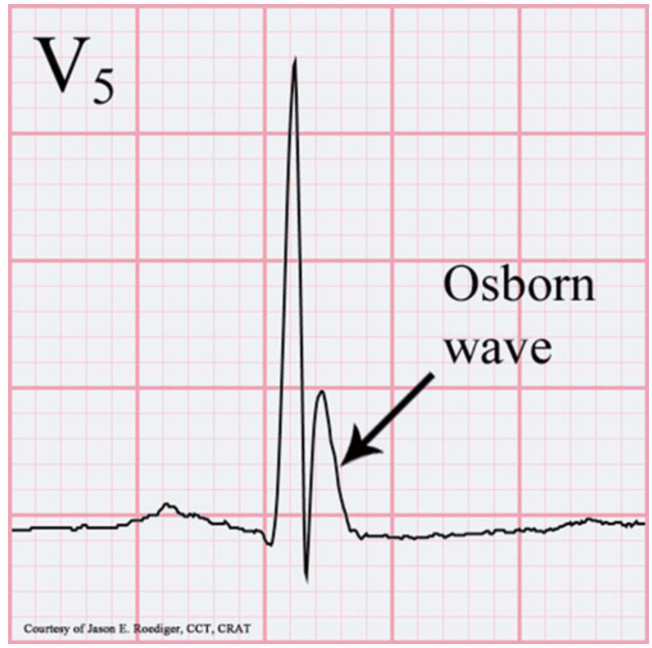

Fig. 30.1 Osborne J wave. Illustration courtesy of Jason E. Roediger, CCT, CRAT. Used under the terms of the *GNU Free Documentation License*, Version 1.2 or any later version published by the Free Software Foundation

Hypothermic patients have diminished respiratory effort, an ileus, cold diuresis with inability to concentrate the urine, mental status changes and hepatic and haematologic dysfunction resulting in bleeding diatheses. There are hemoconcentration (with an elevated haematocrit), thrombocytopenia, uraemia, hyperglycaemia and acidemia.

Cold Injuries

Pathophysiology of Cold Injuries

Freezing Cold Injury

Freezing cold injury, also known as frostbite, is an example of local peripheral cold injury. The pathological process can be divided into two discrete entities: freezing and thawing. The freezing component is due to a combination of extracellular ice crystal formation with a subsequent development of intracellular osmotic pressure gradient differences resulting in cellular membrane disruption, dehydration and death. The thawing process causes microvascular changes including erythrocyte sludging, microthrombus formation, increasing compartment pressures and decreased blood flow leading to tissue hypoxia and necrosis [6].

Table 30.1 Degree of frostbite injury

Clinical appearance	Degree	Outcome
White to yellow firm plaque	First	No tissue loss but causalgia pain may follow
Superficial blisters containing clear or milky fluid with or without erythema and oedema in surrounding tissue	Second	Limited superficial skin loss may occur
Deeper blisters containing red or purple fluid or darkly discoloured skin without blisters	Third	Varies with depth of injury
Extensive dark and cyanotic skin without blisters or oedema	Fourth	Gangrene within a few hours

The table was published in Plastic Surgery, Chapter 26: Cold Injuries, Robson MC Smith DJ, p. 849–66, Copyright Elsevier, 1990. Used with permission [7]

There have been two methods of describing the extent of freezing cold injury: one describing the degree of injury [7] (Table 30.1) and the other describing the depth of injury.

Because of the difficulty in assessing the differing degrees of injury, Mills and associates [8] proposed the terms superficial and deep injury instead of the traditional degrees:

- Superficial injury—limited to the skin and conforms to first- and second-degree injuries.
- Deep injury—involving tissues below the skin, including tendon, nerve, blood vessel and bone. This conforms to third- and fourth-degree injuries.

Nonfreezing Cold Injury

Nonfreezing cold injury is an injury of the hands and feet that results from prolonged exposure to wet conditions and temperatures just above freezing. It is predominantly due to microvascular endothelial damage, stasis and vascular occlusion. At first, the tissue is cold and sensate, progressing to anaesthesia in 24–48 h. The hyperaemic phenomenon is accompanied by an intense burning sensation as well as blisters and possible ulceration [9].

The present view is that nonfreezing cold injury is brought about by prolonged vasoconstriction. In the normal human physiological response, peripheral vasoconstriction is brought about by a sympathetic response. When cutaneous blood vessels are cooled, they become more sensitive to catecholamines, and the arterioles and venules constrict [10]. It is also worth noting that this response is mediated by genetic components as well as acclimatisation. Native peoples in the arctic show much less vasoconstriction than European settlers with cold water exposure. It would be natural to assume that this process would continue in prolonged cold exposure. However, the body endeavours to prevent prolonged peripheral ischemia by a complex series of pathways resulting in a protective cold-induced vasodilation [11]. This phenomenon disappears quite quickly in the initial cold exposure in individuals who obtain nonfreezing cold injury.

Clinical and experimental studies have also demonstrated that cold exposure can be a direct cause of peripheral nerve injury. A widespread, predominantly distal degeneration of axons has been documented, leading to nerve dysfunction and damage to sympathetic nerve fibres [12]. There has been no conclusive evidence that certain types of nerve fibres are more at risk than others. Various studies have hypothesised that small unmyelinated fibres are more at risk than large myelinated ones and vice versa [13, 14].

Management

Management of cold-related injuries depends very much on the situation and the location at which they are being treated. Other factors must be considered, and gunshot wounds, shrapnel wounds or overt haemorrhage must obviously take priority over the management of cold weather injury.

There are three main principles of management for cold weather-related injuries:

- Prevention of heat loss
- Slow restoration of normothermia
- Preventing the precipitation of cardiac dysrhythmias

The obvious treatment modality for cold injury is prevention. This requires a holistic approach. In the cold, it is not advisable to get fatigued until exhaustion, sweat excessively, wear tight and/or wet clothing, drink alcohol, smoke or expose oneself unnecessarily to wind, metals or fluids [15]. Prevention encompasses adequate clothing [5], optimal medical health and adequate hydration, preventing inactivity and prolonged exposure to the cold environment [16].

Once under medical care, hypothermic patients should receive care directed at restoring the traditional A-B-C's. Patients may require intubation or supplemental oxygen administration. Prior to considering initiation of cardiopulmonary resuscitation, an extended pulse check should be undertaken due to the presence of severe bradycardia and hypotension that is typical in hypothermia. Patients should have temperature monitoring, administration of intravenous fluids, gastric decompression and urinary catheterisation in addition to rewarming.

The method of rewarming depends on the severity of the hypothermia, the cardiac response and presence of a perfusing rhythm and available resources. Passive external rewarming (raising the ambient temperature) is appropriate in only the mildest forms of hypothermia. Active external rewarming, which includes application of forced-air blankets, can rewarm the patient approximately 2 °C/h. Finally, active core rewarming is reserved for the most severe cases and includes extracorporeal techniques that are appropriate for those in extremis. Rewarming may cause compartment syndrome, rhabdomyolysis and acute renal failure, pulmonary oedema and coagulopathy.

In some patients, rewarming does not initially seem to restore normothermia as their core temperature continues to decline. There are two possible hypotheses why this occurs:

- Conductive explanation
- Convective explanation

The convective theory is relatively straightforward and explains this by the increase in cardiac output and vasodilation which in turn returns cool blood from the extremities causing the so-called "after drop" phenomenon. On conductive heat loss, the core is warmer than the periphery, so a temperature gradient is established. Therefore, rewarming does not immediately correct this, as warming occurs in a central to peripheral process.

Rewarming shock is a phenomenon that refers to cardiovascular collapse as the patient is warmed. It is due to peripheral vasodilation and increasing metabolic demands of tissues now that normothermia is being established and the cardiac output being unable to meet tissue demand.

As the temperature drops below 30 °C, the risk of ventricular fibrillation increases as the heart becomes more physiologically unstable and sensitive to stimuli. This is partially due to a decrease in the fibrillation threshold. There are multiple theories to explain this observation, including acid-base disturbances, ischemia, and myocardial temperature gradients.

The initial management of freezing injury may be considered as two distinct entities: pre- and post-thawing. Thawing is stated to be complete when the distal component of the thawed body part flushes. Pre-thawing management involves the frostbitten extremity being placed in a bulky protective dressing and elevated. This has the main benefits of keeping the area warm as well as acting as a mechanical barrier to prevent friction and shearing forces which may lead to degloving of the friable tissues. Local rewarming should begin only if refreezing will not occur in transit [17].

The treatment of freezing cold injury involves rapid rewarming by complete immersion of the frostbitten part in water [6] at a temperature between 32 and 41 °C (90–106 °F). This rapid rewarming may lead to reperfusion, which may be extremely painful to the patient; therefore, potent forms of analgesia may be required including opiates.

If the injury involves the lower extremity and there is no evidence of overt sepsis, then epidural analgesia may enable pain to be adequately controlled. Transcutaneous electrical nerve stimulation (TENS) may also provide some relief and allow a multimodal analgesic regime to be instituted.

There is a risk of compartment syndrome developing due to rewarming. If this is suspected, then fasciotomies are indicated. Diagnosis of compartment syndrome may be difficult due to pain being masked by the already existing cold weather injury; therefore, there must be a low threshold to perform fasciotomies. In the event of a long evacuation time, prophylactic fasciotomies should be considered.

Management of frostbite blisters is controversial. Some advocate their removal because of the high concentrations of prostaglandin $F_2\alpha$ and thromboxane A_2 in the exudates [18]. However, the removal may predispose exposed tissue to desiccation; therefore, when blisters have formed, they should be left alone. If very large, the blisters should be aspirated. If the blisters have exposed a raw surface, then once a medical assessment has been undertaken, silver sulfadiazine solutions may be applied to aid healing.

When the injury is deep and severe, the extremities are kept on clean sheets with cradles over the injured regions to prevent trauma, not too dissimilar to methodologies used to treat burns. If the injuries have oedema present due to accumulation of intercellular fluid secondary to rewarming, then elevation of the affected limbs is encouraged. It is also advisable to encourage digital movement to prevent digital oedema from occurring.

Overall, the key is to treat the patient in a multisystem manner and not just the affected area of cold injury.

Key Points

- Cold weather injuries should be suspected in any individual who has suffered from prolonged exposure to the elements.
- Care should be taken in rewarming to compensate for "after drop" and "rewarming shock".
- Tissue should not be debrided if there is absence of sepsis in cold weather injury.

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War Zones and Biological Warfare

31

Jason D. Heiner and Peter Moffett

Introduction

Medical providers who perform trauma care in the unique settings of a war zone or while facing the threat of biological warfare agents encounter dynamic barriers to individual and trauma team performance in addition to exceptional threats to their safety and that of their patients. Thoughtful appreciation of the obstacles to trauma and medical treatment in the war zone or when confronted with agents of biological warfare can prepare the trauma provider and the trauma team to optimize their delivery of patient care.

War Zones

War zone trauma providers generally train in civilian and noncombat military settings prior to engaging in battlefield medical care and often have little or no experience in the combat setting prior to their first medical war zone assignment [1–3]. When not deployed to the combat setting, urban civilian trauma hospitals provide an ideal environment for training military trauma teams due to the relative high volume of injured patients at these centers [1, 2]. While the dynamics of trauma team care in the war zone and nonwar settings share some similarities, notable differences to care within the battlefield exist.

On the battlefield, the individuals composing trauma teams and the specific circumstances in which trauma care is provided can vary considerably. Trauma care occurs along a spectrum from battlefield care at the point of injury while under enemy fire and with minimal medical resources to larger mobile or fixed structures that resemble more familiar emergency care and resuscitation environments. War zone trauma care in the American military and similar modern military systems utilizes a tiered trauma care and evacuation system to organize and deploy its medical resources (Table 31.1) [4, 5]. The first echelon of care is near the point of injury with trauma care teams often consisting of combat medics or battalion aid station personnel. Care at the second echelon takes place in settings such as the forward surgical team, mobile field surgical team, and expeditionary medical support unit where immediate life- and limb-saving surgical interventions and stabilization may occur. The third echelon of care occurs in settings such as the Army combat hospital, Air Force theater hospital, or Naval fleet hospitals—combat trauma casualties may arrive to this level of care from the first or second echelon of care and, from here, may be transferred out of the war zone. These levels of care are connected by medical evacuation services to transport patients efficiently up or between these echelons of care. The varying levels of care allow treatment of minimally injured patients at the lowest tier of care needed in order to maximally maintain local war-fighting strength, while also providing key opportunities to stabilize more critically injured patients prior to their transport out of the war zone.

Members of modern war zone trauma teams can include varying numbers of surgeons and surgical specialists, emergency physicians, combat medics, anesthesiologists, nurses, and additional ancillary providers (Table 31.1) [4–8]. The multidisciplinary physician nature of modern robust military trauma teams provides optimal care to combat casualties and addresses the frequently devastating penetrating, blast, and orthopedic injuries seen on the battlefield. Radiologists may aid in the triage of imaging studies for trauma patients and report immediate results to trauma team leaders. Many additional providers assist in patient care at the higher echelons including blood bank, pharmacy, laboratory services, and operating room personnel. In multi-casualty and mass-casualty

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Table 31.1 Levels of common war zone patient care settings and typical trauma team member composition [4, 5]

Level I (*i.e., point of injury*)
Combat medic
General physician
Physician assistant
Level II (*i.e., forward surgical team*)
Combat medic
Nurse
Surgeon
Anesthesiology provider
Level III (*i.e., combat support hospital*)
Combat medic
Nurse
Physician assistant
Surgeon (including specialists)
Emergency physician
Anesthesiology provider
General physician
Radiologist

incidents, the trauma team members vary based on number of casualties and the priority and nature of their injuries.

War zone casualties can include soldiers, adult civilians, children, and enemy combatants and often arrive with little warning, in critical condition, and in multi-casualty or mass-casualty numbers. Team preparedness to ensure effective communication, identified leadership, role clarity, situational awareness, and action anticipation is imperative. The ability of the individual and the trauma teams to function in a predictable manner to dynamic situations is key to care in the combat setting. Team training prior to combat deployment, ongoing training in the war zone, and consistent debriefing are vital to optimizing battlefield care.

Pre-deployment simulation-based training has positively affected trauma team performance in areas such as modern battlefield injury care, individual performance awareness, and team performance during mass-casualty incidents [3, 9, 10]. Importantly, pre-deployment training can identify critical areas of needed improvement in trauma team performance such as communication lapses, inappropriate trauma triaging, delays to lifesaving procedures, and failure to recognize hazards such as unexploded ordnance [11]. In the war zone, ongoing team exercises and simulation-based training can be an effective tool to maintain and improve trauma team performance and may be particularly valuable to orient new members to the deployed trauma team. Team exercises can target critical events, can complement debriefing tools, and can include all aspects of patient care from initial triage through evacuation to higher levels of care.

Care of the trauma patient can be stressful for care team members in any setting. The consistent high acuity and devastating nature of battlefield casualties within unfamiliar surroundings combined with a setting typically removed from a medical provider's usual personal and professional support can add additional emotional burden. Medical providers in combat settings are at risk of developing syndromes such as post-traumatic stress disorder and should be offered interventions such as critical incident debriefing [12]. Regular debriefing of trauma care as well as critical incident debriefing of particularly stressful events may optimize team and individual performance, enhance individual coping, nurture team communication, and prevent stress reactions or identify individuals in need of more mental health resources.

Biological Warfare

Agents of biological warfare are unconventional weapons considered to be a modern threat in military and civilian settings. Although these agents are relatively inefficient as weapons on the modern battlefield, the relative ease in which they can be obtained, produced, and delivered makes them attractive to terrorist organizations, antagonistic foreign governments, and related entities. Several unique factors make biological warfare situations problematic for the trauma team. The presence of these toxic agents may remain unnoticed for days or weeks due to delayed onset of illness after exposure or when initially being overlooked as the effects of a natural endemic [13–15]. Multi-casualty or mass-casualty events of both victims of these toxic agents and the "worried well" may overwhelm healthcare facilities [13–15]. Patients may require critical decontamination to mitigate further effects of such poisoning to include preventing the spread of these agents to healthcare providers as secondary casualties [13–15]. Care of the trauma patient in the setting of biological warfare can be optimized by an understanding of some aspects of these rarely encountered agents as well as unique considerations of their impact to the trauma team dynamics.

Biological warfare agents are generally infectious and often living particles [13, 14]. Most of these entities can be categorized as bacterial, viral, or toxin in nature and are generally most efficiently weaponized as an aerosol (Table 31.2). There are a great number of bacterial organisms which include anthrax, cholera, and plague, while viral agents include smallpox and viral hemorrhagic fevers, and weaponized toxins include ricin and *Clostridium botulinum* spores. A myriad of physiological derangements may manifest after exposure to these agents and may complicate the spectrum of care of the trauma patient (Table 31.3).

Casualties of biological warfare agents could easily overwhelm the capacity of any civilian or military healthcare system. In general, healthcare facilities and their providers are thought to be poorly prepared for these unexpected events that could quickly deplete resources for these casualties that are expected to require extended care [13, 15]. Members of

Table 31.2 Selected biological warfare agents, likely mode of delivery, and chosen physiological effects [13, 14]

Biological agent	Delivery mode	Physiological effect
Bacterial		
Anthrax (*Bacillus anthracis* spores)	Aerosol release	Pulmonary, gastrointestinal, cutaneous
	Food and water contamination	
Brucellosis (*Brucella* bacteria)	Aerosol release	Bone and joint, pulmonary, genitourinary
Plague (*Yersinia pestis* bacteria)	Aerosol release	Pulmonary, hematologic
Cholera (*Vibrio cholerae* bacteria)	Aerosol release	Gastrointestinal
	Food and water contamination	
Viral		
Smallpox (variola major or minor virus)	Aerosol release	Skin, pulmonary, hematologic, neurologic
Viral hemorrhagic fevers (i.e., Ebola)	Aerosol release	Skin, hematologic, neurologic
Toxin		
Clostridium botulinum toxin	Aerosol release	Neurologic, gastrointestinal
	Food and water contamination	
Ricin	Aerosol release	Pulmonary, gastrointestinal
	Food and water contamination	
Trichothecene mycotoxin	Aerosol release	Hematologic, neurologic, pulmonary, gastrointestinal
	Food and water contamination	

Table 31.3 Suggested precautions and personal protective equipment (PPE) against selected agents of biological warfare [13]

Precautions and PPE	Biological agent
Universal/standard precautions	Anthrax Cholera Clostridium botulinum toxin Ricin Trichothecene mycotoxin
Include gloves, masks, gown, eye protection, and frequent hand washing	
Contact precautions	Brucellosis
Universal/standard precautions	
plus patients' isolation in a standard room	
Droplet precautions	Plague
Universal/standard precautions	
plus contact precautions	
plus N-95 or better respirator	
plus mask worn by patient	
Airborne precautions	Smallpox Viral hemorrhagic fevers
Universal/standard precautions	
plus patient isolation in a negative pressure room	
plus N-95 or better respirator	
plus mask worn by patient	

the trauma team must expect to treat both contaminated and uncontaminated patients, prioritize trauma care interventions in addition to medical care for the biological agents, and efficiently deliver this care while protecting themselves from secondary exposure.

Care of the trauma patient with exposure to biological warfare agents is complicated by medical management precautions needed to prevent further exposure and disease. There is limited data or consensus to firmly guide recommendations, but if the biological agent is identified, specific precautions should be considered (Table 31.3) [13, 15]. When agents of biological warfare are suspected but not yet identified, personal protective equipment (PPE) with a non-encapsulated chemical resistant suit, gloves, boots, and a full-face organic vapor/high-efficiency particulate air (HEPA) filter cartridge mask has been recommended [13, 15].

PPE is thought to create barriers to patient care including limiting maximum duration of work availability, adding the risk of heat stress, introducing variable limitations in visibility from fogging of eyewear and face shields, and impeding fine motor work and palpation abilities from glove use [16]. Some limited, primarily simulation-based, studies on resuscitative care of contaminated patients report inconsistent conclusions. Studies of civilian emergency department resuscitation of contaminated patients while donning restrictive PPE (such as modern respirators, non-encapsulated chemical resistant clothing, thick gloves, and boots) have often reported negligible overall effects on resuscitative tasks [17, 18]. In contrast, similar studies often taking place in military settings have reported significant reduction in working ability [19, 20]. These limited findings underscore the importance of training healthcare providers prior to such critical events in both the PPE and the environment in which they are likely to encounter the patient and perform team functions. More restrictive PPE is expected to hinder communication among trauma team members and further emphasizes the importance of team training.

Patient decontamination after exposure to an agent of biological warfare may serve to mitigate further effect from the primary exposure as well as limit the effects of secondary exposure to other casualties and healthcare providers. Because there will likely be delay from exposure to presentation, it is thought that extensive patient decontamination may not be needed. Exceptions include discovery of unidentified contaminates or suspected persistent aerosolizable agents such as toxins or anthrax spores [13]. For most agents, removal of clothing and washing of the patient with soap and water to remove further biological contaminates are likely adequate [13]. Wounds can be irrigated with copious clean or sterile water to remove the agent and assist in the removal of contaminated foreign bodies [13]. Patient decontamination should not interfere with more immediate lifesaving treatments and may be performed in parallel with other medical and surgical interventions [13, 15]. The additional task of patient decontamination is expected to place a burden on the performance of the trauma team in manners such as redistribution of provider resources and unexpected delays and unpredicted events in patient care. Trauma team training with explicit inclusion of decontamination scenarios is critical to preparing team members for additional communication requirements, exceptional situational awareness, and role clarity that will be needed in these crisis-rich events.

An easily overlooked consideration in biological warfare attacks is the psychological effects for both the community and the providers involved. It has been well documented that mass population scale attacks cause a large number of noninjured patients to seek care at the emergency department [14, 15, 21–23]. Some of these patients have stress reactions, while others have psychosomatic complaints mimicking the biological agent effects [14, 15, 21–23]. Further complicating such scenarios is the psychological toll these events could have on the providers who must deal with unfamiliar protocols, rare disease processes, a large number of concerned well, the media, and facing the personal risk of possible exposure to a biological agent during an immensely unfamiliar and potentially tragic event. Hospitals and trauma team leaders are wise to have well-defined and practiced protocols in place to manage large numbers of unexposed patients and also to provide rapid psychological support for trauma team members during suspected attacks of biological agents [14, 15, 23].

Conclusions

Treatment of the trauma patient in unique settings such as the battlefield or with the addition of exceptional hazards such as agents of biological warfare presents challenges to trauma team performance. Patient care in war zones is challenged by limited resources, threats of combat, and variable team member composition. Biological warfare agents can have a myriad of physiological effects on the patient, and necessary medical precautions and decontamination events can impair the delivery of typical individual and team care. Targeted trauma team and individual preparation can optimize the delivery of patient care in these exceptional settings.

Key Notes

- War zone trauma care may occur in a variety of battlefield settings with differing medical assets and trauma team members with various medical backgrounds.
- Team training prior to deployment to the combat zone and ongoing training while in the war zone are critical to optimizing team dynamics in this unpredictable setting.
- Regular debriefing and critical incident review may enhance trauma team and individual performance, enhance individual coping ability, prevent stress reactions, and identify those in need of more related resources while providing care in this uniquely stressful setting.
- Biological warfare agents can cause a myriad of physiological effects complicating the care of the trauma patient.
- Physically restrictive personal protective equipment and patient decontamination tasks add challenges to delivering effective trauma team care not typically encountered in general medical settings.

Disclaimer The views expressed are those of the authors and do not reflect the official policy or position of the United States Army, Department of Defense, or the United States government.

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Nuclear Injuries

32

Mansoor Ali Khan and Heidi L. Frankel

Introduction

Trauma care can be challenging in the best of environments. However, in certain circumstances the environment can contribute to the severity of injuries or even cause unique and characteristic injury patterns. Herein we discuss fallout from nuclear disasters or nuclear weapons.

Historical Background

Survivors of the atomic bombing of Hiroshima and Nagasaki in 1945 provide the basis for much of the available literature on the effects of radiation. The Atomic Bomb Casualty Commission (ABCC) was established in 1947 to study the late effects of radiation [1]. There were more than 100,000 documented fatalities as a direct result of radiation exposure [2] following the bombing.

The Chernobyl disaster resulted in 31 immediate fatalities from acute radiation sickness and approximately 6,000 deaths from cancers due to radiation exposure. Almost 4,000 km^2 of land is now uninhabited with 120 villages and two major cities left to decay with over 100,000 losing their homes [3].

Information on early internal radiation doses in Fukushima after the nuclear power plant accident on March 11, 2011, is quite limited due to initial organizational difficulties, high background radiation and contamination of radiation measuring devices [4]. With regard to health-care infrastructure, the biggest lesson learned was the impact of evacuating health-care facilities within the emergency planning zones. The vast majority of able-bodied populace evacuated themselves in private or public transportation. There was no medical support provided during transportation of residents to hospitals and care homes. This resulted in deaths directly attributable to lack of health-care provision during evacuation, whereas at this point no life has been lost as a result of radiation, although the long-term effects are still unknown as elevated levels of radiation are still being detected 3 years later [5].

Physics of Weaponry

The most feared and deadly environmental hazards that exist today are nuclear. These include both conventional fission or fusion devices and unconventional weapons known as "dirty bombs."

Fission employs high-density elements, with a heavy unstable nucleus, that subsequently splits into two or more lighter nuclei releasing a vast quantity of energy. The most commonly used substances to bring about nuclear reactions are the isotopes of Uranium and Plutonium, which undergo fission readily. The first uranium-based weapons used were "Little Boy" and "Fat Man", used to bomb Hiroshima and Nagasaki at the climax of the First World War.

Fusion, on the other hand, can be described as the combining of light nuclei to form a heavier nucleus-bearing product, the same process that powers stars. It can be seen as the reverse of fission, but still with the production of vast amounts of thermal energy and radiation. Practically, nuclear power plants and weapons are the only existent environmental hazard. Nuclear reactor incidents require special consideration due to the variety of radioactive material released; radioiodine (I^{131}) can travel over long distances.

Dirty bombs, also referred to as Radiological Dispersion Devices (RDD) are munitions that cause a purposeful

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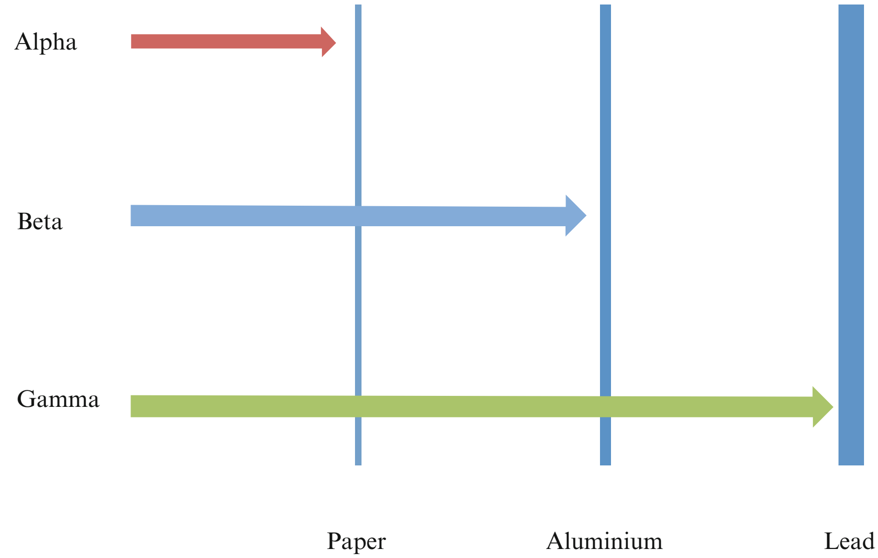

Fig. 32.1 Particle penetration. *Alpha radiation*—readily stopped by a sheet of paper. *Beta radiation*—stopped by an aluminum plate. *Gamma radiation* is eventually absorbed as it penetrates a dense material. Lead is good at absorbing gamma radiation, due to its density

dissemination of radioactive material without nuclear detonation. The purpose of the weapon is to contaminate the area around the conventional explosion with radioactive material.

With thermonuclear weapons, the three main methods of injury from a nuclear explosion result from the initial blast, thermal effects and ionizing radiation

Initial Blast Injuries

These injuries result from the shearing forces between differing tissue planes, causing severe internal tissue disruption. Individuals near the blast epicenter will suffer instant vaporization, whereas the casualties on the peripheries will suffer varying degrees of internal injuries. Petechial hemorrhages within organs are difficult to diagnose, the mainstays are CT/MRI scanning or post mortem findings. The major problem arises not from diagnosing the injury, but once diagnosed, very little therapeutic measures to save life can be administered. Matters are further complicated when debris is carried in the blast wave; the arising result will cause blunt and penetrating injury to occur. In these situations one can only carry out the usual life support measures.

Thermal Effects

The rapidly expanding fireball that develops into the infamous "mushroom cloud" has an initial temperature of many millions of degrees Centigrade. As it expands at a rate of over 100 m/s, it rapidly cools to only a few thousand degrees Centigrade. The thermal radiation emitted can cause severe burns at many kilometers away.

Radiation

The types of radiation are important due to the fact that they affect cellular function in differing ways. Alpha (ά) particles are essentially the nucleus of helium atoms. These have a limited airborne range of a few centimeters, and are easily absorbed by paper. However, due to their relatively high atomic mass, they cause the most structural cellular damage. Beta (β) particles, ideally described as free floating electrons, have a range of a few meters and are stopped by a thin sheet of aluminum. These have an atomic mass of 1/1,850 of a neutron/proton, and therefore, are less destructive compared to alpha particles. Finally, Gamma (γ) Radiation is electromagnetic waves, which can only be stopped by concrete or lead; this allows for deeper penetration of the human body and subsequent internal irradiation (Fig. 32.1).

The scale used for quantitative measurement of radiation is known as the Gray (Gy) scale. The cellular effects of radiation are similar for different kinds and doses of ionizing radiation. Cell death is readily observed by light microscopy, with nuclear and cytoplasmic deformational changes. The type and severity of the injury is dependent on the dose of radiation received. A useful indicator of this is the Median Lethal Dose (LD50 2.5–5 Gy), which is the dose that is lethal to 50 % of a given population.

Medical Management of Nuclear Device Related Injuries: Scene Considerations

There are two ways in which an individual may be exposed to radiation, *external radiation hazard* and the *internal radiation hazard*.

External Radiation Hazard

This is received when the radioactive material is external to the body. Emitted radiation travels through space and irradiates the body; however, the radioactive material remains external to the body. Therefore, if one moves away from the source of radiation, the amount of radiation the body is receiving decreases.

Internal Radiation Hazard

Internal radiation hazard, or radioactive contamination as it is often referred to, arises from radioactive material entering the body. The three main routes of entering the body are inhalation, ingestion, and injection. Once inside the body, the radiation from the contamination irradiates the internal organs. Internal problems vary with the type of radiation that is emitted. If a substance is undergoing alpha decay in the gut, then areas of close contact are being exposed to high-energy radiation that will result in immediate cell death. The half-life of the radioactive substance is extremely important, as some isotopes may linger in the body from a time frame of hours to years [6].

The major difference between the two types of radiation hazard is that in one circumstance, getting a distance away from it can considerably reduce one's radiation dose. With radioactive contamination, the fact that the source is internal, distance from the source would make no difference. To prevent ingestion/inhalation, no eating/drinking or smoking should be allowed until after an individual has left the area and has been decontaminated.

Protective equipment, protocols and procedures should be used for emergency services personnel to eliminate/minimize radioactive contamination. Personal protective equipment provides a physical barrier that allows respiratory protection, and protective clothing that prevents skin contamination. The emergency planning zone for a nuclear reactor incident involves two zones:

- Plume exposure pathway emergency planning zone (within a 10 mile radius).
- Ingestion exposure pathway emergency planning zone (within a 50 mile radius).

Transportation

It is imperative that life-saving tasks be undertaken before moving the casualty. Once completed, then transportation of these casualties can be divided into two groups: those without radiation exposure and those with radiation exposure. Patients without exposure to radiation require no special transport consideration. Those exposed to radiation require removal of contaminated external clothing and covering with two large sheets. Care must be taken to decontaminate the evacuation vehicle.

An initial response team will usually evacuate the casualty to the initial treatment area where the medical team will be given a status on the type of radiation level of contamination [7]. The casualty is then taken through a decontamination procedure in a "dirty area", removing all garments and being cleansed with copious amounts of water.

Once this has been achieved, the casualty is then rechecked for radiation. If contaminants still exist, the casualty is further washed with copious amounts of water and a detergent, and the process is repeated. If radiation-free, the individual is then taken to the "clean area" where he/she can undergo further medical treatment.

Treatment should be extremely limited. For example, intravenous cannulation may introduce radioactive products into the general circulation; intubation may cause radioactive substances to be forced into the upper airways and lung parenchymal tissues. The inhalation of these substances will cause substantial internal radiation, as it is extremely difficult to remove once inhaled.

Ideally, this process must be carried out for all casualties. However, as one can appreciate, if a nuclear device were to be detonated in a large populace, then carrying out the above required decontamination would rapidly use up all available medical resources and present a massive challenge on the command and control structure, especially with regard to who to prioritize for medical treatment.

Hospital Care

Initial management of a casualty, as with any medical problem, is the most important phase. However, this is not as simple as it seems. The priority for the individual is to for decontamination and administration of potassium iodide—to reduce the uptake of I^{131}. This is one of the many daughter products of nuclear fission of Plutonium, and will help reduce the risk of developing thyroid neoplasms.

It is difficult to ascertain what dose of radiation an individual has been exposed to. The diagnosis of radiation sickness is based primarily upon the clinical picture presented by the patient, as radiation dosimetry is unreliable, and also varies based on the organ system primarily affected. Individuals may not realize that they have been exposed to radiation, especially if it is due to fallout.

In order to measure the amount of radiation received, one must obtain samples of sputum, nasal swabs and urinalysis to check for the amount or radioactive contaminants. Whole body radioactive imaging is also available, but this proves to be time consuming.

A relatively simple test to establish the severity of radiation exposure can be obtained by measuring lymphocytes in the blood [8]. An initial sample must be immediately taken within the first 24 h followed by additional samples. A useful rule of thumb is, if lymphocytes have decreased by 50 % and are less than 1,000/mm^3, then the patient has received significant radiation exposure.

Injuries sustained due to the blast wave are directly proportional to the magnitude of the blast. In the majority of cases, the shearing forces between the tissue planes are severe enough to irreparably damage organs/organ systems. Individuals, for example, with blast lung have a very poor chance of survival—the only curative process, would be a total lung transplant. Even if this was the case, it is highly unlikely that the lungs are the only organs to be damaged. People generally die in blast injuries due to multisystem failure.

The major complicating factor in a blast wave from a nuclear explosion is that it is highly unlikely that overpressures will be the sole contributors to bodily damage. It is almost impossible not to have airborne missiles within the blast wave. Luckily, the majority of missile injuries caused by nuclear weapons, will in general, be low velocity in nature and severe injuries may be survived since extensive tissue cavitation would not be a factor. However, greater than 90 % of people who have sustained penetrating trauma and the majority of individuals having sustained severe blunt trauma will have some form of vascular injury.

Key Points

- Nuclear disasters can present with a spectrum of manifestations, each with their own challenges.
- The key is to evacuate casualties and limit exposure to radiation to both them and relief personnel.
- A command center should be established in a non-contaminated region, to assess the extent of damage, contamination and to implement control and treatment measures.

Conclusions

Thankfully the use of nuclear weapons and nuclear disasters are exceedingly rare. However, these incidents carry with them unique considerations from a medical treatment, logistical, and organizational point of view, and each jurisdiction should have a plan in place for such circumstances.

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Trauma and Surgical Capabilities for Space Exploration

33

David J. Alexander

Introduction

Surgeries in space have always been a distinct possibility in the space program. Several studies have been performed to quantify the risk of surgical events in spaceflight using analogues. These studies have shown that illnesses and injuries that require major surgery should be rare [1, 2]. If these events do occur, they can have critical impacts to the mission. These include mission aborts and partial or complete return from low Earth orbit. If these events were to occur on an exploration class mission away from low Earth orbit, the consequences could be devastating. Major surgery, if performed, will impact numerous areas of mission planning and performance. Significant amount will need to be invested in crew training and logistics.

Only noninvasive surgical procedures have been performed on humans thus far. The advantage to being in low Earth orbit is that one can stabilize an astronaut and return in an 8–24 h time period. Throughout the construction phases of the International Space Station (ISS), there was an increased risk of trauma, lacerations, crush injuries, and thermal or electrical burns. The careful planning of the individual phases of construction, with crew safety being a principal concern, resulted in no severe injuries occurring. This is not to say there have not been close calls in the history of spaceflight. On the Soviet space program mission Salyut 7, a cosmonaut experienced severe abdominal pain. This was thought to be appendicitis. This later proved more likely an episode of ureterolithiasis. The cosmonaut recovered and did not require early evacuation. An astronaut on ISS Expedition 30/31 also developed abdominal pain, but was determined by ultrasound on orbit not to be a surgical problem. Numerous minor procedures have been performed aboard the ISS. These principally involve minor superficial lacerations that are common. Although falls do not occur in microgravity, the movement of large masses has resulted in pinched fingers. Uneven surfaces due to excessive use or, in rare cases, bad design have also resulted in superficial injuries.

Exploration missions have an increasing risk of injuries. These are missions beyond low Earth orbit and likely to other planets. The crewmembers will be exposed to gravitational forces that increase the risk of injury. Falls are to be considered in the planning of future missions. The risk of orthopedic injuries will increase with deep exploration missions due to the bone and muscle degradation that occurs in microgravity. The deconditioning in the cardiovascular system also jeopardizes the responses a crewmember can recruit to combat traumatic conditions. Exercise countermeasures to counteract these microgravity effects place the individuals at risk for minor or major orthopedic injuries. Surgical conditions such as appendicitis, cholecystitis, and ureterolithiasis can occur randomly and are a risk for surgical intervention. There is also the possibility that a surgical condition could arise from long duration spaceflight that was previously unpredicted. Wound healing is delayed in microgravity conditions and will affect recovery time. It has been also shown that immunosuppression occurs with spaceflight and may complicate postoperative healing.

Exploration missions will necessitate careful design of the surgical systems and crew training. The driving consideration is the autonomy of the system and crewmembers due to long separation from definitive medical facilities. Communication delays compound the issue as ready availability of consultants may not be possible. The surgical equipment manifested will be limited by weight, power, volume, and lighting in the vehicles. Training on the unique surgical equipment for spaceflight will impact the time a crewmember spends premission in preparation for these contingencies. The crew makeup should include a crew medical officer, specifically trained to handle these situations. Even if a physician is placed on the crew, he will have to maintain the skills required to perform surgical procedures. There is also the psychological

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impact of being confined and the gravity of a fellow member of a close-knit crew requiring surgery.

The effects of solar radiation are a real concern, and much needs to be learned about spaceflight beyond the limits of the Van Allen radiation belts. In the next section, we will explore the physiological challenges of spaceflight. These take a high priority in trauma treatment for any space exploration mission with prolonged journeys in microgravity or total weightless states.

Physiological Challenges in Spaceflight

There are essentially no differences in physiologic responses between microgravity (low Earth orbit and still under the minimal gravitational pull of the Earth) and zero gravity (away from planetary gravitational forces). For this chapter, essentially they will be treated as interchangeable terms. A vast majority of the experience with spaceflight has been in low Earth orbit or the microgravity environment. Astronauts in microgravity have physiological changes that put them at risk for surgical procedures. One of the biggest alterations in space travel is in the cardiovascular system. When the subject arrives in space, there is no longer a gravitational pull that drives the circulatory components toward the feet [3–5]. This results in a shift of fluid from the lower body to the head and torso. Since the cardiovascular system no longer fights gravity for fluid distribution, the stroke volume is decreased 10–20 %. The resultant fluid shift initiates a diuresis resulting in a 10–23 % volume reduction which is roughly equivalent to a grade one hemorrhage [6–8]. These changes are seen in the first 24 h of spaceflight. There is an initial 17 % reduction in plasma volume that is compounded by transiently increased levels of hematocrit. This appears to cause a decrease in erythropoietin secretion causing a reduction in the mass of red blood cells [9]. The net effect is an overall reduction of about 10 % in total blood volume upon entry into the microgravity environment. Cardiovascular reserve is definitely reduced, and the sympathetic responses are altered with greater beta-receptor sensitivity. This has the possibility of preventing the required vasoconstriction needed to combat a traumatic or surgically induced insult [3, 10, 11]. This process is actually started if the astronaut is in a prolonged lying position with the legs elevated above the trunk. This triggers the perceived fluid overload by the kidneys and will activate the concomitant diuresis [12].

Evidence exists that raises the issue of impaired wound healing on orbit [13]. Research done on shuttle flights indicated that incisions performed in microgravity had greater inflammatory responses, fibroplasia, and collagen deposition. There was also evidence of reduced stress loading. During the STS-90 shuttle mission, numerous surgical procedures were performed on rodents. Observationally there was no evidence of dehiscence or infection after 48 h. The incisions made in spaceflight appeared to heal well after surgery [13]. Another area of concern is the loss of bone density with weightlessness. No longer is there a static gravitational load on the skeletal structure. The loads normally imparted by running or walking terrestrially are not present. With lack of a straining force, the bone no longer undertakes remodeling and reinforcement [14]. Other factors that compound the effect are loss of direct sunlight with reduction in vitamin D. Also chronically elevated CO_2 leads to acidosis and reabsorption of the bicarbonate in bone [15–17]. The weight-bearing areas of the bone bear the greatest impact. The lumbar vertebrae, pelvis, femoral neck, trochanter, tibia, and calcaneus lose about 1–2 % per month. A 6-month mission on board the ISS can result in the loss of 8–12 % of bone mass [16]. Individuals display a wide variety in total amount and the sites of bone loss. The supplementation of vitamin D and the use of resistive exercise regimes have definitely made a positive improvement in prevention of bone loss. The demineralization increases the risk of bone fractures on orbit. This also may have an impact on the risk of fracture in travel to distant planets. The likelihood of fracture would increase initially post landing as the astronauts would be required to do work in the new gravitational plane. Terrestrially more than half of trauma cases admitted to hospitals are for long bone trauma [18]. A long-bone fracture on a microgravity mission is potentially disastrous. Experimental bone fractures in microgravity resulted in impaired callus formation and reduced angiogenesis. Bone healing studies of rodents that were placed in orbit on a Russian biosatellite showed decreased osteoblasts, osteoblastic activity, and reduced angiogenesis in the bone [19]. It is unknown at this time if having no static loading will result in malunion. Immobilization would be a simple matter of splinting, but if a traction force is needed, then external fixation would be in order. One advantage to microgravity is that the risk of fat embolization would probably be reduced.

One factor that needs to be accounted for is the immune system and cellular alterations. The cellular immunity seems to be suppressed in microgravity. Consistently neutropenia, lymphocytopenia, and overall diminished white cell populations are seen. On the individual cell level, there are notable decreases in cellular mobility and interleukin production [19]. Also of note is the occurrence of delayed cutaneous hypersensitivity which indicates an alteration of cell-mediated immunity [20]. These alterations in cellular function would have an impact on the initial inflammatory reactions for wound healing. This increases the likelihood of postoperative infections and increases the risk of sepsis. This may also increase the risk of appendicitis, cholecystitis, and other surgical infectious diseases. Add to this the problem of impaired cellular functions is the "contaminated" environment of the space vehicle. A closed environment with little direct sunlight and difficulties in cleaning the environment lead to increases in microorganisms. Observational studies have revealed an increase in the bacterial growth as compared to the terrestrial environment [21]. The bacteria have thicker cell walls to contend with. This adds to the inhibitory and penetration requirements for antibiotics. The bacteria colonies grown from the Apollo-Soyuz mission displayed increased antibiotic resistance as compared to pre- and post-flight colonies [21]. Manifesting antibiotics to combat these consequences would be critical.

There are a large number of issues surrounding surgery in microgravity. These include, but not limited to:

1. Providing and maintaining a sterile field.
2. Maintaining hemostasis.
3. Adequate lighting and exposure—if minimally invasive surgery is used, then adequate visualization by cameras and monitors.
4. Intravenous fluid replacement or blood infusion—examining the pros and cons of blood substitutes and onboard IV fluid generation to reduce up mass of the vehicle.
5. Preventing contamination of the surgical field and the spacecraft—the vehicle likely will use a closed-loop system and will recirculate the atmosphere. Also blood and body fluids have corrosive effects on equipment and surfaces.
6. Providing anesthesia and monitoring.
7. Diagnostic imaging and laboratories required for diagnosis.
   (a) Provisions for ultrasound
   (b) Possible use of endoscopic procedures—laparoscopy, thoracoscopy, cystoscopy, colonoscopy, and esophagoscopy
   (c) Miniaturization of CT/MRI scanners
   (d) Miniaturized and multifunctional lab equipment
8. Accounting for microgravity.
   (a) Restraining the patient and operator to prevent free floating
   (b) Restraining equipment and still readily available in the procedure
   (c) Physiology changes in microgravity—increased risk of intracranial hypertension
   (d) Changes in fluid dynamics that affect the behavior of bleeding and drainage
      – Suctioning
      – Drainage systems modification—functions of cutting and needle insertion will need to be combined with drainage.
   (e) Changes in physical landmarks and shifting of internal organs
9. Modifying advanced life support and defibrillation techniques—limited crew size and space will necessitate compression devices. Also defibrillation will need to be isolated from the vehicle to prevent computer and electrical damage.
10. Waste management—this includes temporary storage during the procedure.
   (a) Contaminated waste
   (b) Needle and sharp disposal
11. Postoperative recovery.

These issues will be explored in more depth in the following sections.

Historical Perspective

Much of the experimentation in surgical capabilities has been with the realization that emergent surgical diseases may occur with prolonged zero-gravity travel. The primary concern recently has been a concern of trauma that may occur with the assembly and maintenance of the ISS. In the future, prolonged zero-gravity transits to planetary surfaces will likely increase the risk of traumatic or emergent surgical conditions. Dr. Iaroshenko experimented with rodents at the Russian Space Agency in 1967 [22]. Since that time, there have been numerous efforts to provide the foundation of surgery in space. The US Space Program history has seen advances in medical equipment and procedures. The Mercury and Gemini programs only carried basic diagnostic equipment to measure physiological changes in spaceflight. Monitoring of blood pressure, pulse, and respirations was a normal procedure. The only medical kits were those deemed necessary for an off-nominal landing in an austere environment. The Apollo spacecraft carried only a rudimentary medical kit for simple medical problems. The Skylab missions had a minor surgical kit to close superficial lacerations [23]. The Space Shuttle medical system had the Shuttle Orbiter Medical System (SOMS kit) and was divided into three parts. One part of the medical emergency kit has a stethoscope, a blood pressure cuff, sutures, disposable thermometers, and medicines that could be injected. The second part of the kit contains adhesive tape, gauze bandages, adhesive bandages, and a variety of oral medicines. The third section contained an instrumentation pack, an oxygen-cycled respirator, intravenous fluid, and a defibrillator. Specialized medicines and equipment could also be added, depending on the requirements of the individual mission. The SOMS kit weighed 20 pounds and could be placed in one of the mid-deck lockers. One of the components was a minor surgical kit for laceration closure. This had conventional instruments that were individually wrapped, which made the logistics of wound closure slightly more complicated than a single sterile pack. Local anesthetics were also included. Items also included in the pack were simple closure items, such as sterile strips, Dermabond ampules, and staples. The hardware on the Mir space station was similar to the Space Shuttle medical system. On board the ISS, the medical system is divided up into sub-packs. Of particular note was

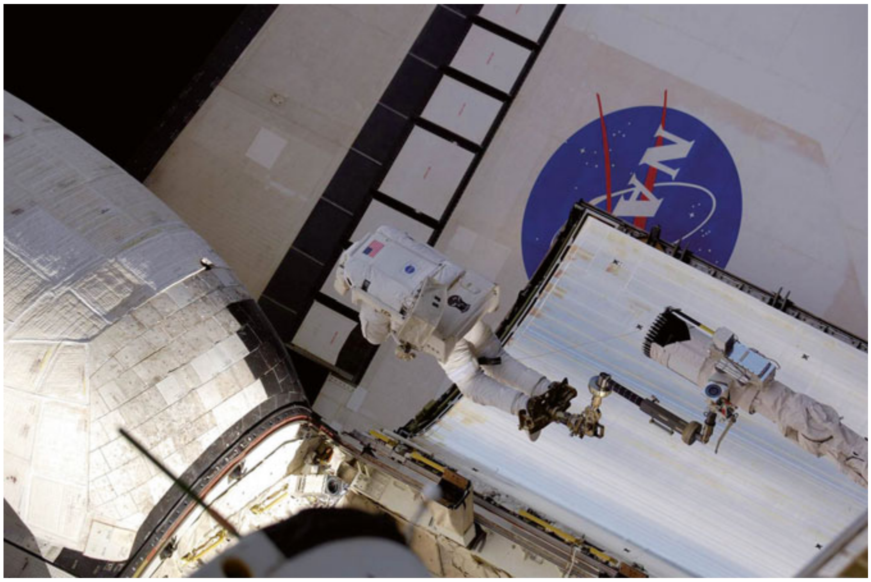

Fig. 33.1 Extravehicular activity during STS-117 to repair the damaged thermal blanket using a surgical staple gun

that the most famous use of the SOMS kit was not in a human laceration repair. On the STS-117 mission, the Space Shuttle Atlantis was damaged during ascent. A corner of the thermal blanket on the port orbital maneuvering system peeled back, leaving a triangular 4-inch x 6-inch gap. The surgical staple gun was used to repair the damage in a spacewalk (Fig. 33.1). It was discovered through testing that the staples could withstand 5000 °F temperatures for a length of time adequate to deorbit the vehicle.

Parabolic Testing

Numerous procedures were validated in human and animal studies on the microgravity aircraft. The parabolic microgravity program uses an aircraft to simulate low gravity states induced by parabolic flight. The aircraft pulls up into a 45° nose high attitude and climbs about 5,000 ft. At that point, the aircraft pushes the nose over to about 45° nose low (Figs. 33.2 and 33.3). At the top of the parabola, a microgravity state is induced for about 20–30 s. The maneuver is repeated 30–40 times in order to simulate spaceflight conditions for equipment and procedure validation. The problem is that it is only a short duration of time to apply the procedures, but this is the only adequate simulation of the microgravity state available currently. Both the Russian and US space programs have used parabolic flights to evaluate medical procedures and equipment. In 1967, the Russian space program evaluated laparotomies on parabolic flights. The system utilized a transparent surgical canopy with a magnetic instrument holder. It was noticed that the procedures went fairly well. The one complication noted was that arterial bleeding formed droplet streams that spread throughout the containment area decreasing visualization. Bowel evisceration during laparotomy could also obscure the visual field [24]. The US parabolic experimental program found that surgical procedures could be performed with only minor modifications. The requirement for restraining the patient, surgical hardware, and the surgical personnel had to be stringently observed [25]. The patient, even if awake for a minor surgical procedure, must remain restrained. The operating personnel must also be limited in motion from the waist down, but leave the arms and hands free of obstructions.

Bleeding and free blood could be contained with common surgical methods of sponges and suction, but must be addressed immediately [26]. All phases of surgical procedures have been evaluated. Prepping, draping, equipment prep, and restraining have all been proven in microgravity. Lighting and enclosed environments have also been validated. Again, the emphasis has been on adequate restraint of the equipment. Glove packages must have tape on the backing to secure them, and commercially available surgical drapes with an adhesive band proved to be excellent solutions for microgravity operations. Conventional antiseptics had enough surface tension to remain in place as well [27–29].

It was found that procedure-oriented kits were preferable to individually packaged instruments. Extra packaging became an encumbrance. Standard Velcro, elastic cords, and magnetic surgical tables helped to contain the instruments. Sharp blocks (a block of Styrofoam for sharps), an adhesive

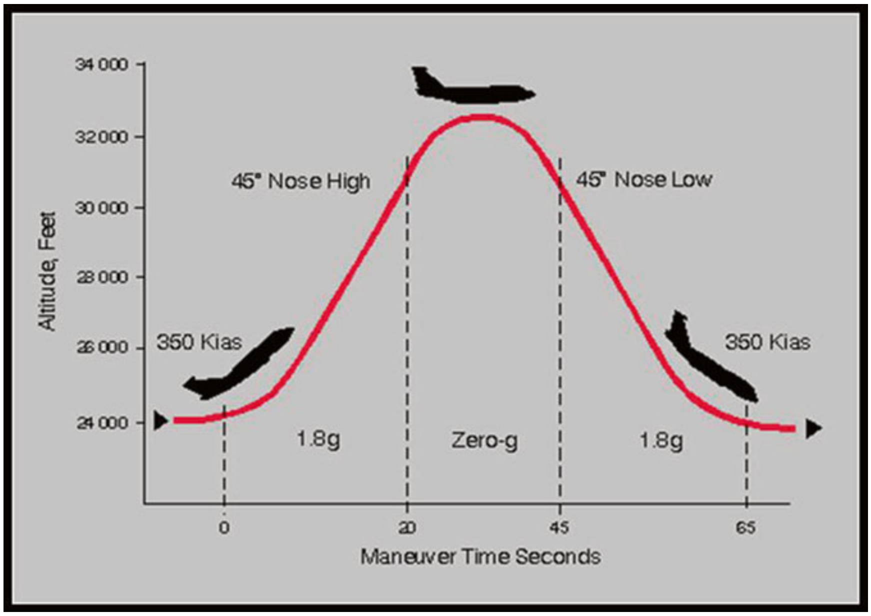

Fig. 33.2 NASA parabolic flight profile

Fig. 33.3 NASA C-9 microgravity aircraft

pad, and a plastic bag near the surgical table or as a pocket on a gown were used to facilitate rapid trash disposal. Maintaining an organized surgical table and rapid trash disposal are critical in the microgravity arena. This facilitated speeding the procedures and maintaining a good visual field [29]. The ISS uses a floor-level restraint system that was developed from similar devices flown on the Space Shuttle and Russian Mir space station. The CMRS (Crew Medical Restraint System) can act also as a backboard for patient transport if needed. It is easily stored and has built-in belts to restrain patients and operating personnel. There is even a built-in cervical restraint system.

Fig. 33.4 Enclosed surgical field testing on NASA microgravity aircraft

Surgical Field Testing

One of the major impedances to surgical care in microgravity (low Earth orbit) or zero gravity (away from planetary gravitational forces) is the atmospheric contamination of the vehicles' atmosphere with blood or other body fluids. The closed-loop systems could easily be overwhelmed with surgical debris and blood [30]. The spacecraft also presents a hazard to the surgical site. The clean vehicle at launch accumulates dross that increases the risk of contamination of the wound area. Particles tend to be larger and contain dust, food particles, and sloughed skin elements. In a limited space environment, the surgical zone may be in close proximity to the galley or exercise facilities. Also there can be numerous scattered areas or waste disposal. This may aid in surgical trash disposal, but it would also be a potential source of contamination for the procedure. Long-duration spaceflight has shown to produce immunosuppression and altered immune responses [31, 32]. Impaired healing of wounds has also been seen. A system for contaminant containment for the field and prevention of infectious contamination of the surgical site are requisite requirements (Fig. 33.4).

The Russian space community built several enclosed systems and tested them in parabolic flights [24, 32]. In 1978, an inflatable Lexan surgical enclosed bubble was proposed by Mutke [33]. Markham and Rock tested several inflatable enclosures and simulated surgical procedures in parabolic flight [34–36]. These proved to be quite successful at containing floating instruments, solids, and fluids. NASA tested a similar inflatable canopy [32]. Anesthetized animals were used as surgical subjects, and the systems were evaluated for ease of use, portability, and containment. It was noted during these experiments that venous bleeding appeared to be increased. It was surmised to be due to an inability of the venous walls to provide compression in microgravity. Unopposed surface tension caused both arterial and venous areas of bleeding to form large fluid domes [26]. Arterial bleeding was not entrapped by sponges or suction when a large stream of droplets was formed. The overhead canopy placed over the surgical area would be useful in containing uncontrolled bleeding or if copious irrigation was required. Another method of containing contaminants in a surgical field is the use of laminar flow devices. The airflow would direct the fluid or other detritus into a downstream suction collection device. NASA also tested this concept in parabolic flight. Bleeding and debris not restrained by local methods were swept away from the visual field directly over the open wound. Still most bleeding was controlled by surgical sponges, gauze, or suction directly at the site.

Surgical and Advanced Life Support Procedures

NASA conducted numerous parabolic flights to test operative and resuscitative techniques in a microgravity environment. These tests were conducted to see what procedures could be done, how the equipment behaved, and if the procedures could be done with minimal equipment. The crew medical officer (CMO) for each journey may be a nonphysician. Cardiopulmonary resuscitation (CPR) was found to be more difficult in lower-gravity environments, but can be accomplished. It was reinforced that restraint of both the subject and the rescuer was critical in most situations. The "handstand" procedure of placing one's feet on the wall opposite to the victim's chest and placing the CMOs hands over his head and on the chest was found to be effective. Also the Heimlich method of standing behind the victim and performing CPR was validated as providing adequate CPR [37–39]. Ventilation support with artificial ventilators was performed, and the parameters were unchanged from the terrestrial environment. Similarly, respiratory mechanics on ventilatory support was not clinically different [40].

ALS (Advanced Life Support) procedures of venous cutdowns, cricothyroidotomies, peritoneal lavages, and chest tube insertions were also evaluated. These proved to be more difficult than in normal gravity. Fluid infusions and drainage systems required modifications to the techniques. Intravenous fluids had to have all the free air removed and required fluid pumps to infuse the fluids. Pressurizing the fluids with external pressure bags did work well. Drainage lines had to be as short as possible and large in diameter to prevent surface tension and capillary action from inhibiting flow. Percutaneous peritoneal lavage was more dangerous. The GI tract is more dilated due to decreased peristalsis in low-gravity environments. This resulted in additional pressure of the bowel on the abdominal wall and increased the risk of perforation. A modification of the technique would be required to increase the air in the abdominal cavity to decrease this likelihood. Another complicating factor was that the increased fluid tension and lack of capillary fluid pull lead to decreased lavage fluid drainage. An advantage to this procedure is that it required less training than their open lavage counterpart. Open peritoneal lavage techniques were accomplished, but required more training and the use of surgical canopies.

Chest tube insertion was also performed on the surgical evaluation parabolic flights. The equipment employed incorporated a Heimlich valve and a Sorenson drainage system. This proved to provide adequate drainage and eliminated the risk of contamination from the vehicle environment. Another advantage was that the blood from a hemothorax in this type of system could be used to autotransfuse a trauma victim [41–43]. A percutaneous Seldinger dilatation method proved easy to train, required only a minimal amount of equipment, and did not require a dedicated surgical field. Suture ties around the chest tube site to secure the tube had to perform several functions and were critical in the procedure. Studies have shown that suturing in microgravity is similar but slower than normogravity [44]. They had to retain the tube in position and control fluid and blood leakage. Chest tube drainage generally did not require suction, because the intrathoracic pressure provided the push to the drainage system. The advantage of a chest tube placed in microgravity was that the hemothorax fluid was equally distributed along the chest wall in an adherent sheet rather than pooling in a dependent location. Some loculation did occur though by surface tension, but overall was not as critical as in a one-G environment. The procedure only encompassed about 1 h of ground-based instruction and could possibly be done by computer-based training (CBT). Telemedicine guidance of peritoneal lavage and chest tube insertion could also be done by a remotely located surgeon.

Other surgical procedures have been performed in the simulated microgravity environment. Leg dissection, thoracotomy, laparotomy, and craniotomy were simulated. Specifically craniectomy, C-section, and laminectomy were conducted on the STS-90 Neurolab flight [45]. Other procedures included ureteral stenting, thoracoscopy, and microsurgery [46–48]. The evaluation of surgical skills in these major procedures demonstrates equivocal results. Subjective evaluation suggests that surgical procedural performance decreases when the operator is not acclimated to the microgravity environment which may further lead to task erosion and subsequent tissue injury.

Numerous evaluations of endoscopy and laparoscopy have been performed [45, 47, 49, 50]. The concerns observed during these procedures were the potential for impaired visualization due to lack of bowel retraction from gravity. Also floating debris of blood and detached materials could impede the visual field. The elastic mesenteric tethering of the bowel in position and fluid surface tension caused surgical detritus to adhere to the abdominal wall. Parabolic flights proved insightful with animal subjects used to simulate the human equivalent. The endoscopic tools and procedures proved to be feasible and comparable to the one-G environment. Abdominal laparoscopy has the advantage of providing a natural surgical canopy by the subject's own body.

The weight of the abdominal wall causes the abdominal cavity to form a flattened oval. This oval in microgravity is changed to a more rounded shape. This leads to an increase in the anterior to posterior diameter and increases the visual field. This actually facilitates minimally invasive abdominal procedures. Other advantages of minimally invasive surgeries are preventing contamination of the cabin with biological particulates, preventing abdominal contamination, maintaining thermal regulation, and possible blood collection and autotransfusion [51, 52].

Minimally invasive surgeries (MIS) have several drawbacks. Thoracoscopy presents a different set of problems from laparoscopy. In the microgravity environment, the retraction of the mediastinum by gravity is not present. This causes anatomical obscuration of the visual field. Selective bronchial intubation, pulmonary segmental deflation, and chest insufflation would be required to make a thoracoscopic procedure viable. It is very difficult to establish a pneumoperitoneum without direct visualization of the abdomen and has a high risk of bowel perforation. Minimally invasive surgeries still remain limited in the management of multitrauma cases [53, 54]. There are numerous publications that have raised the question on the use of MIS in critically ill patients [55–57]. This raises questions if an injured astronaut can tolerate the increased intra-abdominal pressures required for MIS [58]. Astronauts have reduced red cell counts and plasma volumes and decreased cardiac output which put the crewmembers at risk for injury and may be compounded with the stresses of laparoscopy.

In any minimally invasive surgical procedure, the CMO would need to have the training, ability, and experience specific to endoscopic procedures in order to perform them. Highly trained surgeons with considerable proficiency would be required to perform these procedures. Also significant deskilling occurs when a surgeon does not continually practice these procedures. It would require a simulated surgical environment to accompany the mission to remain proficient in these skills. Several studies have been undertaken to reduce the required training and skill-level retention to accomplish minimally invasive surgical procedures. Broderick et al. investigated simulating hand-assisted laparoscopy in parabolic flights [51]. Dulchavsky has also proposed the method of using mini-laparoscopes for peritoneal drainage with telemonitoring [47].

New methods and equipment have been developed making space surgery a more viable and easier option. Miniaturization of laparoscopic equipment has made the possibility of these procedures even more viable. Large amounts of supporting equipment are no longer required for most procedures. A portable computer had substituted for large bulky video monitors, and fiber optics can provide adequate lighting and visualization of the field. Stereoscopic three-dimensional displays are coming on line that can be incorporated into virtual reality headgear. Abdominal wall lift devices are in development that may eliminate the need for CO2 or N2 insufflation [59]. This would allow the abdominal wall to be retracted anteriorly improving the visual field and allow the mesenteric attachments to hold the bowel in place. The change in the abdominal wall shape is different with lift devices than with insufflation. The viscera have a higher propensity to float and obscure the visual filed in the intra-abdominal compartment [60]. Controlling hemorrhage is made easier by fibrin glue injectors, laser scalpels, and advanced stapling devices. Tissue sealants and fibrin glues have been compounded into a foam and easily applied. These have been found to be more effective than surgical packing currently in use [61]. A device now is in development that can detect vascular flow prior to cutting and suturing. This uses pulsatile light absorption characteristics of hemoglobin to noninvasively characterize hidden blood vessels. By using a multichannel LED/sensor pair that employs NIR and red light, blood vessels can be detected and vessel size determined. This would help avoid unintended cuts to the vasculature caused by poor visibility in a minimally invasive procedure. Such a device prevents the obscuration of the visual field by streams of blood caused by inadvertent vessel injury [62].

Accessing disease pathology via an intraluminal route is a revolution in medicine. This has been demonstrated in trauma, vascular surgery, and cardiology care. Access to the central circulation also enhances hemodynamic support and measurements and can enhance guided interventional angiographic therapies. It also can provide an extremely efficient method to administer specific pharmacologic treatments. Via central venous access, inotropes and vasopressors can be administered safely. Vasopressors may be required in the treatment of space-adapted physiology. Heparin-bonded extracorporeal circuits are used in multisystem trauma for both rapid rewarming and also facilitating hemodynamic support [63, 64]. Doppler guided needles are currently available and smart ultrasound-guided "bibs" that use automated algorithms for vascular identification are being developed [65, 66]. In the future, full robotic control may be possible for cannula insertion and diagnostic assessment. This offers some real advantages in deep exploration missions and may reduce the training required for these missions.

Telerobotics and telepresence are offering an increase in precision and the ability to operate from long distances. They offer the capability to enhance the images and dexterity of the individual surgeon. Telemedicine also has the capability to provide consultation and even surgical procedures to be performed from a distance. Investigations have shown that operating across continents and to undersea environments can be accomplished [67, 68]. While these techniques might be practical in low Earth orbit, they would be inhibited by communication delays outside of that realm. A Mars mission could not avail itself of telemedicine. Electronic delays from 8 to 40 min would render this option impossible.

Surgical Procedures in Space

The Space Shuttle Neurolab mission on STS-90 conducted the first surgical procedures on animals in orbit. A leg wound was created and then closed with Dermabond adhesive. Several other procedures were conducted on that mission and provided insight and verified parabolic experiments of surgical procedures in space. The mission confirmed that the procedures were only as difficult as ones performed on Earth. Spaceflight experience also demonstrated that there were no obvious changes in manual dexterity, proprioception, or fine motor control of the hand. It reinforced the principle that restraint of the operator, patient, and surgical equipment was critical. It took a diligent effort to contain equipment in place and immediately discard any trash. Procedures took longer because of the need to assure restraint of the equipment. It was noticeable that fluids coalesced and surface tension predominated in microgravity. Sponging and suction at the site of bleeding controlled the environment and allowed continued visualization of the field. Scalpels and needles required special care, but that restraint on Styrofoam blocks proved adequate. If not restrained, loose needles needed to be called out and identified immediately in order to prevent accidental punctures.

Diagnostics

The physiological alterations that occur in the spaceflight environment will impact disease presentation, diagnostic evaluation, treatment, and management. Ultrasonography has proved to be the most valuable diagnostic tool in spaceflight. Exams such as the extended focused assessment with sonography for trauma (eFAST) to evaluate the need for emergent surgical intervention have been proven on orbit [69–73]. Ultrasound (US) is dependent on gravity to locate free fluid in the thorax and abdomen. Thus far surface tension has caused these to form on orbit, but may not be counted on in all situations. Ultrasound evaluation has been shown to delineate several conditions, including pneumothoraces and sinus fluid levels [72, 74, 75]. The development of three-dimensional US displays has led to improvements in analysis of injuries in acute abdomens. It can better quantify volumes of fluid when compared to two-dimensional US [76, 77]. US contrast media may also be used to help quantify and follow any hemorrhages in real time [78]. Future developments may include the use of integrated computer programs to help predict the progression of an injury. Hoyt's research predicted survivable outcomes based on terrestrial volumes of hemorrhage to be 2 h if the bleeding was determined to be 25 ml of bleeding per minute. If bleeding exceeded 100 ml/min, a mortal outcome could be expected in 30 min if bleeding was uncontrolled [79]. Programs could be generated based on the physiological changes encountered in spaceflight.

US can also be utilized as an interventional device. It has been utilized for guided percutaneous aspiration of intraperitoneal fluid using a swine model in microgravity [80]. US requires user-dependent skills and requires dedicated training for the onboard operators. Current efforts guide less-experienced users from Mission Control using skilled experts who remotely mentor the onboard astronauts. This will require onboard trained ultrasonographers for deep space missions [81, 82]. NASA scientists have created a research program to facilitate minimally trained crew medical officers to use US autonomously and/or using remote guidance [71, 82]. US offers the greatest potential currently, but miniaturized CT or MRI scanners are also being developed that can be adapted for space travel. These will require specialized operators or automated diagnostic tools for immediate analysis. More than likely images can be transmitted back to consultants for analysis. Thus both diagnostic evaluation and interventional techniques could be performed in microgravity with the use of ultrasound-dependent techniques. A noninvasive way to perform surgery is by focused ultrasound. This can be used to ablate or emulsify soft tissue tumors in the tissues of the abdomen, brain, and heart. It offers a method to also treat benign prostatic hyperplasia and possibly bone cancer. Ultrasonic atomization causes mechanical tissue disruption by boiling histotripsy. Ultrasonic atomization occurs by having an ultrasound wave in liquid encountering an air interface. This interaction ejects small liquid droplets into the air. Boiling histotripsy was developed at the University of Washington that uses high-intensity focused ultrasound (HIFU). This HIFU is then used to fractionate tissue into its submicron components. The HIFU rapidly heats tissue as the transducer focuses to form a millimeter-diameter bubble of boiling material in milliseconds. This fractionates the tissue into its submicron components. This technology offers a method of noninvasive precise tissue atomization and is currently being explored for space usage [83].

Trauma Care in Space

Trauma stabilization and care on long-duration or long-distance mission presents unique difficulties in management. In these situations, the need for rapid evacuation can be a disastrous situation. Physiological alterations of microgravity, diminished immune systems, inexperienced or ill-equipped care providers, limited equipment, and extreme distance can conspire against a reasonable survival in traumatic injuries. The advantage to space exploration is that advanced procedures, training, and advanced technology can be incorporated into the design of these missions. These missions are analogous to rural trauma or trauma in undeveloped countries. Rural trauma in the United States shows that in distant populations, mortality can be up to 50 % greater than urban populations. Trauma in rural populations accounts for 60 % of deaths in the US, despite only 20 % of the population reside in these areas [84–86].

Crewmembers in orbit are hemodynamically challenged after 72 h in a microgravity environment. They have about a 15 % decrease in circulating red blood cell and plasma volume. This is defined as a class I hemorrhage terrestrially. Another factor in space physiology that is unique is the blunting of cardiovascular reflexes. These combined result in a decreased ability for a crewmember in microgravity to respond to blood loss. This can result in a shortened time in which intervention can have the greatest effect. They immediately move in to a class II type of hemorrhagic shock. The initial response to trauma must be rapid and consideration to fluid resuscitation must be given priority. As we have seen, ATLS procedures can be readily accomplished in the microgravity environment [40]. Intravenous access has been demonstrated experimentally and aboard the ISS. Securing an airway has also been demonstrated in parabolic flight using endotracheal intubation, laryngeal mask insertion, or surgical tracheostomy. A FAST (focused assessment with sonography for trauma) ultrasound can be utilized to evaluate for traumatic injury as well as confirm the endotracheal tube position [87, 88].

The truncal region requires surgical intervention to control internal bleeding. External pressure is not efficacious to control hemorrhage in this area. Ninety nine percent of deaths are due to thoracic or abdominal bleeding [89, 90]. Ultrasound has been used to localize intrapleural, intraperitoneal, and retroperitoneal bleeding terrestrially, in parabolic flight and onboard space vehicles. It is as sensitive as terrestrial-based applications [69–73, 91]. Management of these injuries has changed due to rapid diagnostic procedures. No longer is explorative surgery required and it has given way to observation and repeated scanning techniques. This also implies that surgical or intensive monitoring must be available in case there is recurrent hemorrhage. Observation may also be complicated by and require interventions in the cases of abscesses, pseudoaneurysms, urinomas, or biliomas. Many of these can be treated with percutaneous interventions and have been demonstrated in parabolic as well as actual spaceflights [80, 92]. These conditions still require surgical expertise if severe recurrent hemorrhage occurs. This would require specialized training and physician intervention [3, 93]. In the space environment, it may be better to intervene in a staged fashion rather than going directly to open procedures. In all of these cases, anesthetics would be required. Gaseous anesthetics have innumerable problems in a closed-loop environment. Re-inhalation and intoxication of the ones performing the interventions is a real risk. Also the incorporation of anesthetic decontamination equipment into the environmental control system may be space and cost prohibitive [3]. Intravenous anesthetic techniques are preferable and have been demonstrated in parabolic flights.

Immediate Damage Control Procedures

Severe shock and sepsis may demand an immediate surgical intervention before extensive diagnostics can localize the condition. A group of flight surgeons, trauma surgeons, and biomedical engineers emphasized that a laparotomy may be required to stabilize a patient prior to further procedures or deorbiting to Earth [94]. As discussed in Chapters 14 and 15, the paradigm of only completing the necessary components via limited procedures is referred to as damage control (DC) surgery. These methods do not require prolonged procedures that tax the patient's physiological reserves. Also these procedures do not require extensive equipment outlays [8, 95]. These procedures are not significantly different from the terrestrial environment. Solid-organ bleeding can be tamponaded with packs around the offending organ. The abdominal wall can be left open for further procedures to follow. An open abdominal wall facilitates converting noncompressible bleeding into compressible visceral bleeding by direct methods. Fibrin glue and tissue sealants can also be used easily in these DC surgeries. These procedures have been demonstrated by physician extenders and non-surgeons [96]. These types of procedures would allow immediate DC surgery to be performed to stabilize the crewmembers condition. Then planning and further diagnostics can take place with consultation with ground control. Then long-distance training or reviews and simulations can be undertaken to perform a definitive surgical procedure.

Orthopedic injuries lend themselves to damage control procedures. Fixation devices are easy to use and may be the most viable option. Plaster casting requires mixing plaster with water and this takes up a valuable resource. Fiberglass casting materials produce large amounts of off-gassed products that must be accommodated by the environmental control system. These may not be easily removed. Flexible aluminum splints and elastic bandages can be used on the simpler fractures. Numerous fractures require gravity to heal the break or maintain reduction. Manual traction is difficult to apply in microgravity. Another concern is that bone healing is likely to be delayed in spaceflight [13, 14]. External fixation offers numerous advantages. The techniques for the most part are simple and rapid. They are not physiologically stressing and do not require extensive anesthesia applications. Their application will allow early mobilization, and if placed under tension, they may substitute for gravity and manual traction. US can be used to diagnose and evaluate the reduction [63, 97, 98]. This has been demonstrated in numerous studies [99–101]. The use of US can also be accomplished with external fixation in place.

Addressing these surgical challenges has led to unique solutions that have been incorporated into terrestrial care [102, 103]. Currently, computerized tomography (CT) and magnetic resonance imaging (MRI) are not done in microgravity environments. An MRI is possible as high-power magnets have been incorporated into the ISS particle physics experiments. The AMS-2 superconducting magnet has 2 coils of niobium-titanium producing a central field of 0.87 teslas. Numerous investigations are undergoing evaluation in the use of advanced US techniques that could be incorporated in the treatment of critically injured patients. These cover a range of subjects from diagnostic studies to addressing the crew training in advanced US techniques [47, 71, 82, 104]. The ISS has an US station aboard to conduct clinical and research efforts in the microgravity environment. The carotid intima-media thickness (CIMT) measurement was developed through a direct venture with NASA. CIMT uses the ArterioVision software initially developed at NASA's Jet Propulsion Lab (JPL). JPL's Image Processing Laboratory is tasked with the processing and interpretation of spacecraft imagery. NASA-invented Video Imaging Communication and Retrieval software has been used to process pictures from numerous space missions, including the Voyagers and Mars Reconnaissance Orbiter. Periodic upgrades of the imaging software have enabled greater accuracy and improved knowledge of our solar system. ArterioVision is incorporated into a standardized US examination of the carotid artery and produces the CIMT [105].

Crew Medical Officers

The CMO (crew medical officer) onboard the shuttle or ISS is not required to be a physician. They undergo 40–60 h of medical training to accomplish specific diagnostic and therapeutic interventions [106]. This includes a broad area of medical subjects, but they do not have the dedicated surgical expertise that a trained physician possesses. A general surgeon with specific training in the unique diagnostic and therapeutic interventions for a long-duration mission would be ideal. Other critical care or emergency physicians would also be excellent candidates. This mission specialist physician would also have other training in psychological support and intervention for a long-duration spaceflight. Their duties would include nonmedical functions in order to equitably distribute the workload of an extended mission. A caveat to this is that the medical specialist would also have the same physiological changes of microgravity and be susceptible to the same risks as the other crewmembers. Another crewmember will need to have some redundancy in capability. Telemedical support is available currently to the ISS, but will be more difficult as the distances grow larger on interplanetary missions. Telemedicine and telerobotics research are constantly ongoing to address many gaps in space medicine care [104]. On these interplanetary missions, acute care will need a large amount of autonomy and a large library of medical information available. Just in time computerized training will need to be available. Also procedural simulation programs can be made available to practice and retain skills. Each mission will have to be scrutinized, and specific requirements and personnel assignments will have to be made with the possibility of a critical medical event likely to occur.

Conclusions

There are numerous advantages of low Earth orbit. In dealing with trauma, having easy communication access to Mission Control and medical consultation resources offers huge potentials. Another advantage is having the option of deorbiting to more dedicated medical facilities. While initiatives to go further than the lunar surface are growing in reality, the option of an immediate return or easy communication with terrestrial resources diminishes with increasing distance. The International Space Station offers unique opportunities to test interventional procedures in order to provide care to traumatized or surgical patients. Landing on other planetary surfaces also increases the risk or trauma due to falls as well as construction injuries as support structures will need to be erected. All of the exploration activities will require dedicated planning to put in place dedicated trauma treatment equipment and personnel. Training will also need to be robust to cover these contingencies. We are explorers and risk takers. In order to minimize the risk, we must plan and test the future capabilities that will extend our reach beyond our terrestrial bonds.

Key Points

- Astronauts in microgravity have a decreased stroke volume, reduced circulating blood volume, suppressed cellular immunity, and impaired wound healing putting them at increased risk from trauma.
- Surgery in space faces many challenges including providing and maintaining a sterile field, maintaining hemostasis, and preventing contamination of both the surgical field and the surrounding environment.
- Imaging in space is also limited and currently relies heavily on ultrasound as the main imaging modality.
- The mission specialist physician on long-duration spaceflights will face multiple challenges including the performance of nonmedical functions in order to equitably distribute the workload, the need for a broad range of medical knowledge, and the ability to retain a specialized surgical skill set with potentially minimal opportunities to practice.

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Part VII

Trauma Team Education

34 Designing a Simulation Curriculum

Jason Park, Reagan L. Maniar, and Ashley S. Vergis

Simulation-based education offers great opportunities for learners in medicine and the health professions. It can be used to teach cognitive or technical skills in a safe environment that is focused on experiential and reflective learning. Too often, however, attention is focused on the simulators themselves and their associated technology. It is important to keep in mind that simulation is an instructional medium, and simulators function only as tools in this context. The focus should not be on the tools, but rather on the educational experience they enable. It is therefore necessary to ensure that simulation is thoughtfully incorporated and appropriately used within an educational curriculum in order to maximize its educational impact.

For the purposes of this chapter on trauma team training, simulation will refer specifically to "simulated clinical immersion" (SCI) [1]. However, many of the curriculum design principles that are discussed can be applied to other simulation modalities as well. SCI involves guided experiences in simulated environments, often with the use of human patient simulators. These experiences are aimed to complement and improve real patient experiences for learners. The distinctive feature of SCI is that the environment reproduces the actual clinical or work environment and directly affects the educational experience. SCI can be used to reproduce the high acuity, dynamic and often fast paced environments that characterize the operating room, trauma bay, or emergency department. This simulation modality is an especially valuable method of teaching the nontechnical skills involved in trauma team and crisis resource management, including situational awareness, clinical judgment, decision-making, interpersonal behavior and teamwork, and stress management. These skills are essential to competently and efficiently manage trauma situations that present in clinical practice.

Designing an educational curriculum to effectively incorporate simulation can be a daunting task. There are multiple steps that contribute to an effective educational program and it requires an organized and well thought-out approach. Many authors have written entire books on curriculum development for medical education, some of which are included in the references [2, 3]. The frameworks described by these authors share common steps or components. With a focus on competencies and educational outcomes, the present chapter follows Sherbino and Franks's five-step framework for systematic educational design (Fig. 34.1) [3]. This chapter serves as an overview of the basic steps that are involved in curriculum design, with a focus on how these steps apply to simulation. These steps include: (1) conducting a needs assessment, (2) developing learning objectives, (3) selecting and implementing appropriate instructional methods, (4) assessing learning and competence, and (5) evaluating the educational program. Some of these steps are further described in the chapters that follow, including Chaps. 35, 36, and 37.

Needs Assessment

The first step in designing a relevant, comprehensive, and effective educational program is to conduct a needs assessment (NA). This serves as the foundation from which the curriculum structure flows. The curriculum's goals and objectives are written based on the results of the NA. The instructional methods are then chosen to meet these goals and objectives.

NA refers to the systematic process of collecting and analyzing information to define the educational needs of the target group [4]. The NA can target individual learners or entire programs. The main point of the NA is that it makes systematic a process that before was largely based on assumptions. The NA identifies the target group's learning needs. Learning

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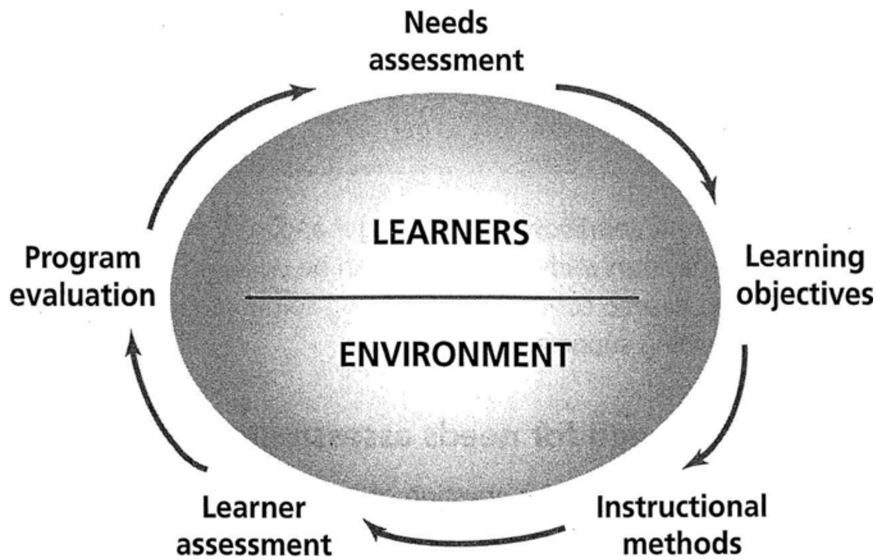

Fig. 34.1 Systematic educational design. Source: Sherbino J, Frank JR. Educational design: a CanMEDS guide for the health professions. Ottawa: Royal College of Physicians and Surgeons of Canada; 2011 [3]. Reproduced with permission

needs refers to the gap between a learner's current and desired ability that can be overcome by a learning activity [5].

Learning needs can be considered from several viewpoints including the learner, educator, institution (including accreditation or licensing bodies, specialty societies, or hospitals) and society [6]. Historically, educators often adopted the idea that they knew best the learner's needs. However, taking the learner's perceived needs into consideration not only addresses gaps that the learners themselves identify but may also increase their engagement in the learning activity. Ultimately, it is necessary to strike a balance that considers the perspectives of learners and educators, and also ensures that institutional and societal perspectives are represented.

NAs can be conducted using information from a number of different sources (Table 34.1). Each source has its own complexities, advantages and disadvantages, and resource requirements. Some of the desired information may already be in existence and easily accessible. In other cases, it may have to be acquired, which may add time and costs to the process.

Sources of information that are commonly used for NAs include external sources, internal sources, as well as data generated from questionnaires, surveys, or interviews. These information sources are further described below:

1. *External sources* include literature searches for original studies, reviews, or practice guidelines; published reports or statements from accrediting bodies (e.g., CanMEDS Roles put forth by the Royal College of Physicians and Surgeons of Canada or the core competencies defined by the Accreditation Council for Graduate Medical Education); and the results of accreditation surveys. External sources are often a good starting point because they can be fairly encompassing, yet readily available at a low cost.
2. *Internal sources* refer to data from within the institution that can be used to identify learning needs. These data sources include direct observation and faculty assessments, mortality and morbidity rounds, examination results from previous student cohorts, and chart audits. Some of this data may already be available at the institution level, but the quality can be variable and the data usually has to be repurposed and reinterpreted.
3. *Questionnaires, surveys, interviews or focus groups* can be used to gain insight into the learner's, educator's, and other stakeholders' perspectives. These tools can be used when the available information is insufficient or when there is a need to collect new or more specific information.

The scope of the intended curriculum, including the type, purpose, and available resources guide the specific information sources selected for use in the NA. In practice, it is best to use these information sources in combination and take into account data from multiple different sources. This approach can enhance the educator's understanding of the target group's learning needs and ensure the curriculum's relevance and comprehensiveness.

Learning Objectives

The next step in designing a curriculum is to transform the learning needs into learning objectives. Learning objectives are clear statements of the intended outcomes of the specific learning activity [7]. They state what the learner will be able to do after the learning activity that they could not do before [8]. Learning objectives are related to learning goals but are

Table 34.1 Information sources that can be used for a needs assessment

Source	Description	Strengths	Weaknesses
Questionnaire or survey	Set of written questions or items	• Low cost, relatively easy to administer • Can assess wide variety of topics and sample a large population • Quantitative and/or qualitative data	• Skill is required to write questions because the quality of data is dependent on the design and quality of the questions • Time and costs of administering, collecting and analyzing data • Responses may be difficult to generalize without an adequate response rate • Self reported data
Individual interviews	Individual face-to-face or telephone interviews	• Useful to get in-depth insight into participants' perspectives • Can allow for open ended questions to assess broader range of topics or clarify/elaborate on responses • Qualitative data	• Resource and time intensive; requires trained interviewers to collect data and often high level expertise to data analysis • Often sample a limited number of participants • Self reported data
Focus group interviews	Group interview, usually 4–10 participants per group	• Allows interviewing several participants at a time • Many of the same advantages as individual interviews but group interaction can allow participants to express perspectives that they might otherwise not express in individual format • Qualitative data	• Resource and time intensive; requires trained interviewers and often high level expertise to analyze data • Data can sometimes be skewed by participants who dominate the discussion • Some participants may be reluctant to disclose information in nonanonymous group settings • Self reported data
Internal environmental scans	Examination of data generated within the organization; sources of data can include: • Course evaluations • Faculty assessments • Performance data from previous student cohorts • Mortality and morbidity rounds • Chart audits	• Much of this data has already been collected (with the exception of some chart audits)	• Data quality and utility can be variable • Data must be reinterpreted and repurposed • Chart audits can sometimes be time consuming and costly
External environmental scans	Examination of externally generated data; sources of data can include: • Accreditation surveys • Literature searches • Reports or practice guidelines from accrediting bodies or professional organizations	• Can provide a starting point for data collection • Can be low cost since data is usually already collected and accessible • Can identify new topics from outside organizations	• May not be applicable at local context • Data may have to be reinterpreted and repurposed
Strategic planning	Activities can include: • Review of organization's mission and vision • Reviews of survey and interviews, internal and external scan results • Brainstorming of participants and stakeholders	• Usually involves a range of participants and stakeholders, including learners, teachers, educators, and administrators • Allows leadership to develop and prioritize needs • Useful for large scale curriculum development or renewal	• Resource and time intensive; requires skilled leadership and facilitation

Adapted from: Ratnapalan et al. (2002)[4], Kern et al. (2009)[2], and Sherbino and Lockyer (2011) [6]

more specific. Goals are broader statements about the overall purpose of a curriculum. They are more general and more difficult to measure. In contrast, learning objectives are specific and designed to be more easily measured. Achieving the specific objectives should contribute to achieving the overall goals of the curriculum.

Learning objectives are important for learners and educators in that they set specific expectations for the outcome of the learning activity. The objectives also guide the selection of learning methods and help to prioritize content. Finally, learning objectives enable assessment and program evaluation to demonstrate the effectiveness of the curriculum.

Table 34.2 Examples of learning objectives using observable action verbs

• "At the end of this simulation session, second-year general surgery residents will identify the causes of hemodynamic instability in patients who sustain blunt abdominal trauma"
• "At the end of the simulation course, workshop participants will demonstrate the standard technique for chest compressions"
• "At the end of this simulation scenario, trauma team leaders will be able to describe the factors associated with poor compliance with advanced trauma life support guidelines in the resuscitation room"

Well-written learning objectives have five elements:

1. A *defined learner*. Objectives should describe "who" they are intended for. This description is especially useful for simulation sessions that involve multiple learners at different levels or from different backgrounds who may have different learning objectives. Furthermore, learning objectives should always be written from the learners' perspective.
2. A *time reference* during which the learning occurs. For example, objectives may apply to a single simulation session or a series of sessions, or to an entire training program.
3. A *performance description* of what the learner should be able to do. A key point when writing performance descriptors is to use action verbs that identify an observable behavior. Observable action verbs provide clear and more precise guidance for learners than non-observable verbs. They are also easier to assess. Examples of observable action verbs that apply to skills required for trauma team management include "identify," "list," or "demonstrate." In contrast, non-observable verbs, like "appreciate" or "understand," are vague for learners and difficult to measure.
4. The *conditions under which the learner will learn*. The educational tools that are provided or can be used are defined.
5. The *criteria for assessing performance*, including the minimal standard for assessing performance.

In some cases, the learning objectives will need to specify each of these elements in detail. In others, some of these elements may be implied. Table 34.2 lists some examples of learning objectives that incorporate these elements. The focus of learning objectives should always be the learners' performance at the end of the learning activity.

Instructional Methods

After establishing objectives, the next step in designing an educational program is to develop content and choose the most appropriate instructional methods to achieve the objectives. Several factors need to be considered when choosing instructional methods for any curriculum. These include: (1) the domain of the objectives and competencies of interest, (2) the number of learners, their backgrounds and levels, (3) the learning environment, and available resources and expertise, and (4) practical issues associated with implementing an instructional method, such as the time frame.

There are a number of different instructional methods, and some methods are more appropriate for certain objectives than others. Ultimately, it is necessary to select the instructional methods that best achieve the desired learning objectives. To create appropriate training opportunities using simulation, it is necessary to select objectives from your broader needs that can be met using the available simulation technology.

Simulation can be used to teach and assess a range of roles or competencies. It offers the opportunity to bring members of a healthcare team together in a simulated environment, which makes it an ideal platform to teach and assess team processes and outcomes. Consequently, simulation is an especially effective method to teach crisis resource and trauma team management skills like situational awareness, clinical judgment, decision-making, communication, leadership, teamwork, and inter-specialty or inter-professional care. Participants can learn and practice these skills in a structured, safe and supportive learning environment without compromising the safety of patients. Simulation-based training has been shown to improve crisis management nontechnical skills, and quality of care in high acuity situations [9, 10]. The main disadvantage of simulation is that it is only useful for certain types of objectives, so it is crucial to match the learning methods to the type of objectives of interest. Simulation can also be expensive and resource intensive, so it is important to engage leadership early in the curriculum development process to build and maintain support for the program.

Simulation sessions usually have three main parts: (1) a briefing in which the participants get acquainted with the setting, the case, and the available resources, (2) the exposure to a simulated scenario and (3) the debriefing in which the participants get feedback from the facilitators or preceptors. Because simulation involves active participation from the learner, the learner should have at least some previous experience with the topic. Before any session, the teacher should familiarize him or herself with the characteristics of the learner, their training (specialty or discipline and level of education), and previous experience with the topic in question.

The scenarios used in simulation courses form the core of the educational experience and their development is discussed in the next chapter. The debriefing session is also an essential part of simulation-based education. The debriefing session gives learners the opportunity to receive feedback and reflect on their performance. The feedback consists of identifying performance gaps, determining the basis of these gaps, and then targeting instruction to close the gaps. It is intended to be constructive and to stimulate reflective practice, focusing on improvement rather than being judgmental or critical.

Simulation for Assessing Learners

An assessment plan for learners is an integral part of a well-developed educational curriculum. Assessment follows the instructional method, which in turn flows from the curriculum's goals and objectives.

Miller previously proposed a framework to assess clinical performance or competence [11]. In his framework, the achievement of competence follows a hierarchical progression from "knows," to "knows how," to "shows how," to "does." Simulation provides a realistic environment where learners must apply and integrate knowledge, skills, and decision-making abilities in real-time. By placing learners in this environment, educators can evaluate competency in a way that more closely reflects actual clinical practice compared to other learning methods. In particular, simulation offers educators the opportunity to observe and assess learners' ability to "show how."

Simulation can allow the assessment of multiple skills or roles within a single testing session. Trauma simulation is particularly useful in testing decision-making (medical expert role), teamwork (collaborator role), and communication skills (communicator role). When planning assessments for trauma scenarios, it is not necessary to assess all the roles all the time. It is more appropriate to use specific tools to assess specific objectives for a particular scenario or program. For example, some simulation scenarios may teach medical expertise and communication, and assessment should focus on these roles in these cases. It would be inappropriate to assess roles that did not play a large part of a given scenario.

The choice of assessment tool should match the type and stage of the learning being assessed or taught. In other words, the complexity of the assessment tool should match the complexity of the learning objective. Furthermore, the assessment tools should have evidence to support the reliability and validity of their results. Finally, the assessment needs to be practical to administer with the resources available.

Program Evaluation

Program evaluation refers to a systematic process of reviewing an education program. The most important question when conducting a program evaluation is whether the program achieved its intended goals and objectives. Through this process, educators can decide on whether to continue a program or identify changes that may be needed to improve future programs. Program evaluations also help educators decide whether the program justifies the resources allocated to it.

The program evaluation process has three main components: (1) determining the elements to be evaluated (what to evaluate), (2) selecting the best approach and tools to conduct the evaluation (how to evaluate), and (3) analyzing the data so that decisions can be made about the program. There are several established frameworks for program evaluation that can be applied to simulation-based education, such as the Kirkpatrick Hierarchy (Reaction, Knowledge, Behavior, Results) or CIPP (Context, Input, Process, Product) models [12, 13]. Program evaluations can be based on one or several of the levels or points within these frameworks. The specific tools for evaluation can include questionnaires or semistructured interviews, structured observations, and examination results. The extent of the evaluation must be consistent with the size of the educational program and the resources available to conduct the evaluation. Last but not least, the intent of the evaluation will determine the types of decisions that can be made on its basis. Program evaluation results are most commonly used for continuous quality improvement.

Conclusions

Simulation can play an important part of a system aimed at improving performance and enabling high quality care for trauma patients. However, simulation by itself is merely a means. The success of any simulation activity ultimately depends on how simulation is incorporated and used within a broader educational curriculum.

Designing a comprehensive, cohesive, and effective educational curriculum entails several key steps. Curriculum design usually starts with a needs assessment, which serves as the foundation from which the rest of the curriculum structure flows. The curriculum's goals and learning objectives are developed based on the results of the needs assessment, and instructional methods are then chosen to best meet these goals and objectives. The objectives also facilitate the assessment of learning. Finally, program evaluation should be planned as part the curriculum design process to evaluate the effectiveness of the curriculum.

Key Points

- The success of any simulation activity ultimately depends on how simulation is incorporated and used within a broader educational curriculum.
- Curriculum design usually starts with a needs assessment, which serves as the foundation from which the rest of the curriculum structure flows.
- The curriculum's goals and learning objectives are developed based on the results of the needs assessment, and instructional methods are then chosen to best meet the goals and objectives.
- Learner assessments and program evaluation should also be planned as part the curriculum design process to evaluate curriculum's effectiveness.

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35 Designing Multidisciplinary Simulations

Peter G. Brindley, J. Damian Paton-Gay, and Lawrence M. Gillman

Introduction

Readers who have progressed through this text have learnt that (a) trauma can be chaotic and that complexity, unfamiliarity, and stress can make it error-prone. Therefore, (b) practitioners need a combination of knowledge, psychomotor skills, and behaviors (the three, so-called, Bloom's domains) [1, 2]. Accordingly, (c) trauma education needs to be deliberate and comprehensive, and simulation is ideally suited. However, just like resuscitation, simulation is not always as easy as "a,b,c." Therefore, this chapter is not just about doing more simulation; it is about doing more simulation right.

Background

Error in medicine is inevitable and ubiquitous [3]. Simulation is ideally suited to address error, but is no panacea: it is only as good as its curriculum, its design, its facilitators, its fidelity, and its debrief. Moreover, simulators and simulations are not yet sophisticated enough to completely replace real patients. "Done right" and simulation can supplement clinical experience and help practitioners refine their performance. Done wrong and it can be a waste of scarce time and resources and can annoy overtaxed clinicians. Therefore, this chapter discusses how to design simulations that are educational, realistic, reproducible, and a valuable investment of finite resources.

It is worth stressing that some form of simulation has long been central to medical education [2]. This has included "what if" questions, practicing chest compressions on Annie Dolls and using actors as standardized patients. Moreover, medical training has always involved graduated decision-making and supervision with feedback [2]. As such, simulation is not new and, therefore, should not be feared. What have changed are the available technologies (mannequins and task trainers), the inclusion of adult education principles ("don't just tell me; show me"), an increased focus on training the entire multidisciplinary team, and a move toward competency-based evaluation (rather than just volume-based or time-based). Modern simulation is not a new direction, but an ongoing evolution. To quote the Hitchhiker's Guide to the Galaxy: don't panic! [4].

Simulation 101: General Principles

We define "medical simulation" as any technique that recreates clinical situations to allow training with minimum patient risk [5]. Simulation can then be divided into high- or low-technology, high- or low-fidelity (i.e., the degree to which it is realistic: see below), or by the platform used (role playing, standardized patient, computer-based, task trainer, full body simulator, virtual reality immersion, etc.) (Table 35.1) [6, 7]. This chapter focuses on mannequin-based team simulation. Regardless, it is worth emphasizing that the *simulator* (i.e., the task trainer or mannequin) is a small part of the total *simulation* (i.e., the experience of immersion in a simulated environment) [6, 7]. Simulation is a technique, not a technology [6–8].

Optimal simulation requires realistic settings (the area used to represent the clinical environment), able facilitators (those involved in the design and administration of the simulation), and skilled debriefers (experts in clinical content,

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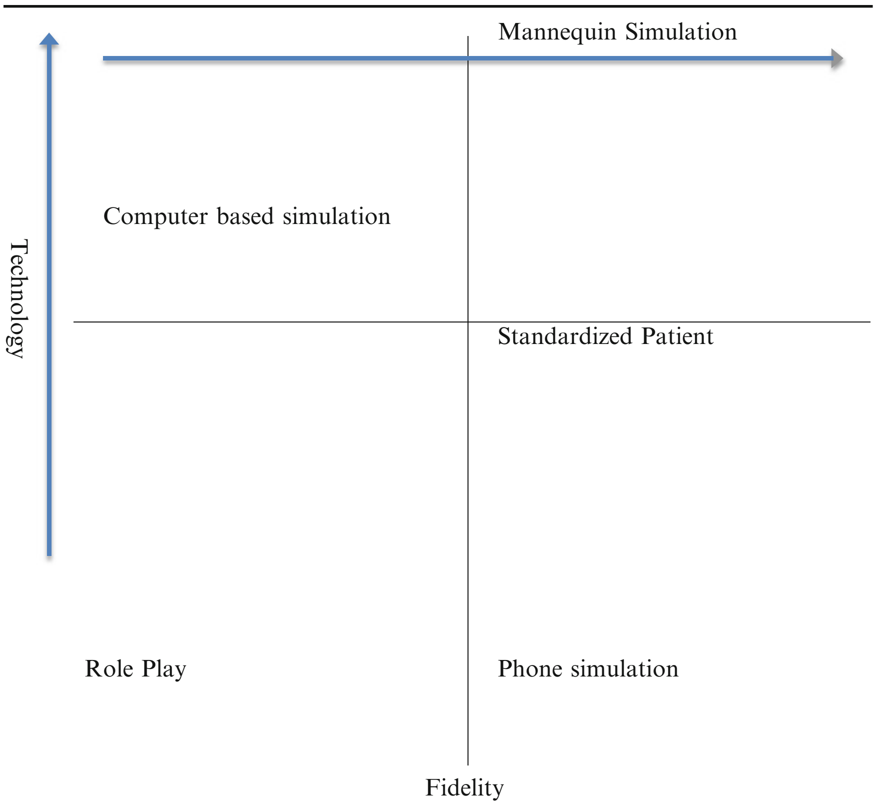
Table 35.1 Technology and fidelity in simulation



adult education theory, and crisis resource management (CRM) – see Chap. 34). As above, "fidelity" refers to the extent to which the simulation resembles reality [9]. Traditionally, energy and technology were focused on mimicking the physical environment. However, we really need to optimize fidelity in three domains: physical; functional, and psychological [10].

Physical Fidelity

The physical fidelity is the degree to which simulation recreates the look, feel, sound, and smell of the real world. This includes both human and inanimate resources (i.e., both personnel and equipment). In trauma, this means ensuring that the simulated trauma bay contains the necessary equipment and that it is laid out in the usual fashion. Simulations can be performed in the actual clinical location or can employ photographic backdrops of your own trauma bay or operating theater, prerecorded patient sounds, and monitor noises.

Simulations have long included moulage makeup and fake blood. A recent addition is to cover the mannequin with a powder that only shows under ultraviolet light (to help teach universal precautions and hand washing). Recipe books also exist that provide instructions to make simulated vomit, melena, sputum, etc. [11]. This is more than gimmickry; after all, we learn best when we use all of our senses: sights, sounds, and smells.

Functional Fidelity

Functional fidelity refers to how realistically the simulator reacts to input from the operator. In other words, when an action is taken, does the simulator respond in a realistical manner? For example, following decompression of a tension pneumothorax, the oxygen saturation should improve rapidly. If not then participants may find the experience unbelievable.

Psychological Fidelity

Perhaps the most important part of fidelity is psychological. This represents the participant's emotional response or "buy-in." For example, does the simulation produce similar excitement, stress, or fear as real trauma, and do participants respond realistically? Maximizing psychological fidelity can be challenging, but the first step is to optimize physical and functional fidelity. Next, we can add complexity to the scenario (see below) or increase the environmental cues (e.g., phone ringing, audible warning on patient monitors) [10].

The extra effort helps learners to suspend disbelief. This increases engagement, which may improve knowledge acquisition and retention. A helpful analogy can be to liken simulation with drills used in sports training. Although there are no pylons on the playing field during games, the ability to navigate courses made of pylons can improve the players' agility. In this way the game can be broken down into component parts and each skill honed ahead of game day.

Overcoming Obstacles to Simulation

Obstacles to simulation, such as "performance anxiety," must be appreciated [12]. Educators should ensure that all participants feel safe to learn, to make mistakes, and to learn from mistakes. One strategy is for all simulation instructors to also become regular simulations instructees (i.e., do not expect others to do what you will not do yourself). In addition, when teaching juniors, we should ensure that we do not overwhelm or scare. When teaching seniors, we should ensure that we do not underwhelm or bore. Simulation should be individualized just like treatment [2].

In the early days of mannequin simulation, there was a tendency to tell learners that they could not make mistakes. These authors believe this is no longer justified. After all, our goal is to duplicate clinical practice where errors are commonplace [3]. The difference is that simulation allows us to learn from these mistakes in an environment that is safe for both patients and learners. We are less likely to remember cases that went right, compared to when a wrong decision, or missed cue, resulted in a poor outcome. Therefore, these are key educational opportunities. Seeing the effect of our mistakes helps shape future actions and provides an impetus to self-improvement. When designing simulations, we need to instill a sense of responsibility, just as we need to mirror the inescapable stress of trauma. With this in mind, it is critical that simulation scenarios not be designed solely to "stump" or expose the trainees. Careful design increases the likelihood that the required behavior or response is brought out by scenario. This is turn allows for a more deliberate debrief.

Appropriate criticism (from teachers to learners) has been showed to be just as important as achieving the hallowed "10,000 h" of practice [13]. If we are "too soft," then there is a danger that we provide excuses that, in turn, prevent reflective learning. If we are "too hard" (or fail to accept the limitations of simulators), then we will destroy confidence or learners ignore instructors. A useful construct is the Yerkes-Dodson law [14] (Fig. 35.1). This inverted U-shaped curve compares performance (y-axis) and arousal (x-axis): too little arousal impairs learning and retention, as does too much stress or criticism [14, 15].

Simulation champions should be wary of giving the impression that those who teach traditionally, or were not trained using simulation, are "out-of-date." Also, due to cost and time constraints, many hospitals only employ simulation sessions once or twice per annum. If the goal is for simulation to drive systemic change, then sessions should be regular [5]. The more that simulation becomes integrated into everyday hospital practice, the more that participants will see this as a normal, nonpunitive, activity.

Before embarking on simulation, both facilitators and learners can agree on a "fiction contract." Originated by Dieckmann et al. [16], this establishes the terms of the simulated session. It outlines roles and responsibilities and can be verbal or written and informal or formal (Fig. 35.2). The contract states that facilitators make the scenario as realistic

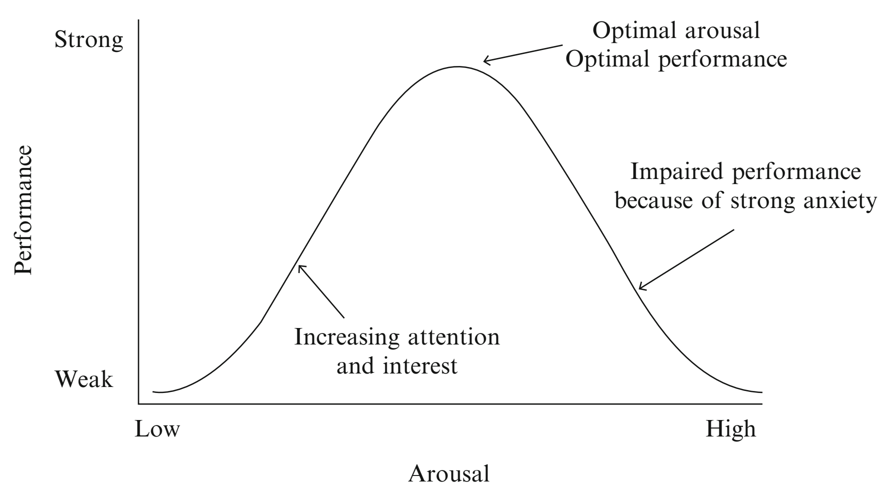


Fig. 35.1 Hebbian Yerkes-Dodson law: designing simulations that are neither too easy nor too hard. (Redrawn with permission from: Diamond DM, Campbell AM, Park CR, Halonen J, Zoladz PR. The Temporal Dynamics Model of Emotional Memory Processing: A Synthesis on the Neurobiological Basis of Stress-Induced Amnesia, Flashbulb and Traumatic Memories, and the Yerkes-Dodson Law. Neural Plasticity 2007: 33. doi:10.1155/2007/60803. PMID 17641736. Copyright © 2007 David M. Diamond et al.)

Sample Simulation Fiction Contract

The purpose of simulation-based healthcare training is for you to develop skills, including judgment and reasoning, for the care of real patients. Using patient simulators and simulation teaching techniques, your instructors will recreate realistic patient care situations. The realism of each simulation may vary depending upon the learning goals for the session. The simulated environment and patient have certain limitations in their ability to exactly mirror real life.

When participating in the simulations, your role is to assume all aspects of a practicing healthcare provider's professional behavior. Additionally, when a gap occurs between simulated reality and actual reality, it is expected that you try to understand the goals of the learning session and behave accordingly.

Instructor Responsibilities:

- Create goal-oriented, practical simulations based upon measurable learning objectives.
- Add enough realism to each simulation so that the learner receives enough clues to identify and solve a problem.
- Set and maintain an engaging learning environment.
- Provoke interesting and engaging discussions and fosters reflective practice.
- Identify performance gaps and helps close the gaps.

Learner Responsibilities:

- Suspend judgment of realism for any given simulation in exchange for the promise of learning new knowledge and skills.
- Maintain a genuine desire to learn even when the suspension of disbelief becomes difficult.
- Treat the simulated patient with the same care and respect due an actual patient.

Learner's Signature	Instructor Signature
Date	Date

Laerdal helping save lives

Laerdal Medical authorizes the
unrestricted reproduction and modification of this sample form

Fig. 35.2 Sample fiction contract. Reprinted with permission from Laerdal Medical as possible. In return, participants will "suspend disbelief" and act as if it was a real clinical situation. It means that all agree that simulation has limitations, but all agree to maximize learning.

Simulation 201: Basics of Scenario Development

Whether designing a traditional curriculum or a simulation curriculum, many of the same lessons apply (Table 35.2). Firstly, learning objectives should be clearly stated and should use action verbs ("learners will do the following…"). Secondly, the work of Bloom is particularly instructive. Bloom described a taxonomy of educational objectives that includes three domains: cognitive (knowledge and recall), psychomotor/skills (thinking and doing), and attitudinal (behaviors and reactions) [1, 2].

When designing simulations, we can ensure each scenario includes at least one learning point from each of Bloom's domain. For example, in major hemorrhage, the factual learning point may be that we now employ massive transfusion protocols. The manual skills may be how to set up a level 1 infuser, and the behavior may be how to advocate for immediate surgery. This strategy can be readily applied to any critical incident (i.e., in head trauma: how to dose mannitol, how to perform hyperventilation, how to direct the trauma team). Just as a stool needs three legs in order to stand, this three-legged simulation approach (fact, skill, and behavior) sets simulation apart from traditional education.

Bloom's work offers more regarding simulation design. For example, for senior learners we may focus more on the attitudinal domain. For junior learners, we may focus more on the cognitive domain. Depending upon how junior learners are, we can further subdivide the cognitive domain into six levels of increasing complexity. These include "facts" (can trainee repeat/write what they have learnt?), "understanding" (can trainees put the facts in their own words?), "application" (can trainees apply the facts to different cases?), "analysis" (can trainees locate relevant information?), "synthesis" (can trainees put it together/come up with a plan?), and "evaluation" (can trainees compare and evaluate different plans?) [1, 2].

Table 35.2 Steps of scenario design

• Identify baseline skills of the learner(s); identify clinical needs of the learner(s)
• Tailor the simulation to match those needs
• Include at least one new skill from each of Bloom's educational domains
• Tailor the simulation (more cognitive skills for juniors, more attitudinal for seniors)
• Further tailor the simulation (low-level cognition for juniors, higher level for seniors)
• Especially for mature learners, consider including:
– Telephone simulation, handover simulation, blindfolded simulation
• Allow repetition of the same scenario until mastery
• Always leave time for structured debrief
• Compare performance before and after (i.e., Ottawa Global Rating Scale)
• Collect data; welcome candid feedback

Experience is a great teacher, and, as such, scenario development will likely improve over time. It *is* appropriate for educators to use their own clinical scenarios to get started. Moreover, you do not have to be an expert educator to design useful initial scenarios. Instead, you need modest emotional intelligence (i.e., what does the learner need?) and a commitment to ongoing improvement. Simulation is also about preparing people for practice, not reinforcing the superiority of the instructor. Too many scenarios have focused on atypical presentations or have been programmed to cause mannequin death (no matter what the candidate does). The focus should be on what the learner requires not what the teacher wants to teach.

Basic facts can be transmitted in the lecture hall and at the bedside, even in the coffee room. Alternatively, facts can also be taught through medical simulation, and retention may be better than via passive or didactic methods. However, simulators are expensive, not always portable, and frequently require operators. Therefore, mannequin simulators are usually best reserved for nonfact-based education (the so-called nontechnical skills). Instead, facts can be taught during a pre-simulation tabletop discussion or interactive lecture.

More recently, electronic learning systems are increasingly used. These facilitate scheduling, pre-learning, and pretesting. This maximizes simulation time and ensures participants are primed to get the most from finite simulation time. These online tools can include advanced graphics, video, and sound clips, making them at least the equal of traditional textbooks. In addition, online resources can include computer-simulated patients. These can contain varied responses (based on preprogrammed algorithms) triggered by the learner's response. They can also include "nudges" based upon how far participants veer from the intended learning point.

For those learners new to simulation (and to crisis resource management (CRM) training), merely simulating in a team format provides opportunities to address leadership, communication, teamwork, problem-solving, and situational awareness. However, as the learners mature, the goals should be more deliberate. This can be done by preemptively highlighting at least one CRM-specific objective in the scenario design. For example, *the learner will demonstrate situational awareness*. In this case, the scenario would be designed with distractors such as incessant overhead pages, distressed family members, and distracting injuries. Alternatively, *the learner will deal with conflict and leadership*. In this case, a confederate can question the leader's decision-making and try to create dissent. These CRM objectives are then addressed in the structured debrief.

A common error in design is to increase complexity to ensure that the trainees do not "solve" the problem too early. As complexity of the scenario increases, so does the potential for deviation from the expected course, as well as the potential for an overwhelming number of issues for debrief. Careful attention to the educational objective of the scenario is the first step to preventing this issue. At each phase of scenario construction, the writer should ensure that the elements direct learners toward the objective.

As outlined, good facilitators tailor the simulation to the particular learner. Namely, we should determine what baseline performance we expect from learners (to ascertain a suitable starting point) and what level we expect them to reach (to ascertain when the simulation has achieved its goal). The same applies to individualization within the psychomotor and attitudinal domains. In other words, we can "tweak" the scenarios in order to stay level with the learners or just one step ahead. Therefore, we can use the same scenario many times and create a graded curriculum. Learners can also simply repeat the same scenario if their original performance was poor. After all, the goal is to improve learner confidence not destroy it.

Choosing a Clinical Stem and Scripting the Scenario

Next we turn to creation of the clinical summary, stem, or vignette. The goal is to outline the case, the participant's roles, the location, and the local capabilities. You can alter how team members respond by modifying the clinical stem ("you work in the trauma team of a level 1 trauma hospital" vs. "you work in a rural hospital without surgical backup). Next, we describe the events surrounding the patient's hospital arrival. This often mirrors the EMS (emergency medical services) report and includes the events surrounding the injury, initial vital signs, interventions en route, and past medical history.

Following development of the clinical stem, the scenario is scripted. This includes updated vital signs, equipment, personnel, and media (x-rays, electrocardiograms, blood work, etc.). The script describes how the simulation will progress (i.e., planned changes in the patient's clinical status and actions by confederates), the moulage, and how to respond to various actions by participants. It can help to follow a template and script. Samples from the STARTT (Standardized Trauma and Resuscitation Team Training) course [17] are enclosed below (Appendices A and B).

As simulation curricula mature, we should also incorporate basic engineering principles [18–20] (Table 35.3).

Table 35.3 Basic simulation scenario design

1.	Identify major problem areas (i.e., an audit or needs assessment)
2.	Use borrowed or bought simulations or use own clinical scenarios
3.	Get input from all relevant experts
4.	Draft a scenario/curriculum
5.	Refine the curriculum (typically using a modified Delphi approach)
6.	Alpha test, using small numbers of learners
7.	What went well (and what did not); was it useful?
8.	Beta test, using larger numbers of learners
9.	Commit to regular review
10.	Share with others

For example, a template for curriculum development starts with identifying major problem areas (i.e., an audit or needs assessment). Next, input is required from all relevant experts (i.e., experts in clinical content and simulation). Next, a curriculum is drafted (typically using a modified Delphi approach). Next, the curriculum is "alpha-tested," using small numbers of learners [18–20].

Following an initial simulation, a structured debrief (in this case, debriefing the scenario design not the participant's performance) should explore what went well and what did not. This helps establish whether the scenario needs to be modified. Accordingly, simulation becomes more than just novel education, but rather a deliberate and ever-greening experience that is (a) more reliable than random patient presentation and (b) more structured than ad hoc teaching. This is why simulation has been described as a "revolution in healthcare" [5, 21].

Simulation 301: Novel Additions to Simulation

Maximizing Simulation Scenarios

Online simulation scenarios can be purchased or shared via free, online, repositories [22]. Each of these scenarios can be further "tweaked" and therefore used for learners at many levels. For example, the same stem can be used ("a 44-year-old female one week post-tib-fib fracture now has a pulmonary embolus"); however, the case can be used for multiple groups by making (1) the vital signs normal, (2) the vital signs moderately abnormal, and (3) the vital signs critically abnormal. Similarly, the patient can have no contraindications to therapy or many gastrointestinal bleeding or recent surgery. The diagnosis can be (1) obvious, (2) one of only two or three options, or (3) impossible to ascertain (thereby forcing treatment before diagnosis). Finally, the available help (both equipment and personnel) can be present, absent, or obstructionist.

Telephone Simulations

Trauma often involves large distances and low population densities. This means acutely ill patients are routinely transported before definite treatment. Much care is coordinated by telephone, but blind communication skills are rarely deliberately taught. Telephone simulation provides many of the putative benefits of high-fidelity simulation but with little cost [23]. For example, no mannequins are required, and logistics are minimal: only two telephones in different locations. Simulated calls can be done within the same hospital (i.e., operating theater to emergency room) or across 100s of simulated miles (a rural physician phoning for advice). Simulated calls can also supplement a mannequin-based simulation (see below).

Handover Simulation

Handing a patient from one team to another can be perilous (akin to passing the baton in a relay race) [24]. As such, simulations can include forced hand-offs (i.e., the patient moves from emergency room to intensive care unit). Participants can practice both handing-over a patient and accepting a patient. The number of hand-offs can be modified based upon the seniority of the learners. Of note, learners may come to expect simulated patients to deteriorate immediately upon transfer. As a result, they may be artificially vigilant (or mistrusting) early on. Sophisticated simulations often wait several minutes before the patient worsens. This is often the point at which participants become lulled into complacency.

System-1 Versus System-2 Simulation

In nature, two archetypes of attention exist [25–27]. The first is the predator's focused gaze; the second is the prey's scanning vigilance. Physicians rushing to resuscitate an unstable patient exemplify the former. Attention is given only to the most pressing issues. This requires reflexes and more *doing* than *thinking* (i.e., performing a stat surgical airway). This is also known as system-1 behavior. The second type of attention means changing your attention from stimulus to stimulus to avoid fixation errors. It also requires more judgment and more *thinking* before *doing* (so-called system-2 behavior).

Scanning vigilance occurs when physicians are forced to address several issues concurrently, but none definitively. System-2 occurs when contemplation is required. This can include managing many patients at once, reviewing CT scans, interpreting arterial blood gases, or talking with families. Most people experience difficulty shifting from system-1 to system-2, but complex resuscitations routinely require that we do so (i.e., we intubate then review blood work). Therefore, simulations that include the need for both focus and vigilance can be ideal for mature learners (but can overwhelm juniors). Inclusion of both system-1 and system-2 also forces leaders to delegate (as they need to remain in system-1). Accordingly, these sophisticated scenarios help evaluate whether the team is functioning as individuals or as a trusting team.

Blindfolded Simulation

Physician leaders often want to do everything themselves, rather than delegating. Accordingly, they may not communicate what they are doing or why. Equally, nurses and respiratory therapists (RTs) do not always share what they have done or when they first identified deteriorating vital signs. To mitigate this, simulations can be redone but with the physician leader blindfolded [28]. This has been shown to immediately improve CRM skills: physicians elicit more help and confirm that instructions are fulfilled. Interestingly, non-blindfolded team members also perform better: they communicate task completion and volunteer changes in vital signs sooner. This simple intervention also enhances role clarity.

Experience has shown that despite initial misgivings, this simple, cost-free addition to simulation is well received [28]. The analogy can be made that in early undifferentiated trauma, we are "blind" to the diagnosis. This strategy is also useful for trainees working in a second language. This is because blindfolding forces the candidate to focus only on their communication skills. Hopefully, the result is to increase the physician's self-confidence and reassure supervisors [27]. We might even be able to claim that our teams are "good enough to resuscitate blindfolded!"

A Few Notes on Confederates

It is common to use confederates to increase fidelity and elicit educationally relevant behaviors from participants. These can be nurses, physicians, respiratory therapists, housekeeping staff, family, etc. Confederates' roles must, however, be clearly defined, including the extents to which they are to complicate or facilitate the scenario. Without such clear roles and boundaries, confederates often help "too much" in obstructing progress of the team or by providing confusing cues. Scenario developers should carefully consider how the confederates' role can help the learners and facilitators to reach the educational goals. Whenever possible, confederates should perform roles consistent with their professional background.

Creating True Multidisciplinary Simulation Scenarios

As per Chaps. 8 and 9, trauma teams can vary substantially. However, most are multidisciplinary and include physicians, nurses, and RTs. Having all members simulate together makes most sense: after all, this is how teams respond in real life. However, non physician participants are frequently included but only as confederates, rather than as primary learners. While much can be learnt as a simulation confederate, all trauma team members should be treated equally. This means all should enter the simulation without prior knowledge, and all should have their learning needs addressed, not just physicians. This represents a substantial challenge for simulation design and can be mitigated by utilizing a number of simple strategies.

Developing Scenarios with a Multidisciplinary Team of Authors

When developing multidisciplinary scenarios, seeking the input of experts from each of the involved specialties or disciplines can improve the educational experience. Involving all relevant stakeholders from the development level creates a feeling of ownership over the curriculum and improves buy-in and participation.

Creating Discipline-Specific Objectives and Discipline-Specific Tasks

When multiple professions are involved in the same simulation, creating discipline-specific objectives for each of the participants is advised. While there may be crossover in objectives, this approach allows the developer to explicitly tailor the learning experience for each of the participating professions. In addition, by specifically including necessary tasks during the scenario that are discipline specific (e.g., setting up and operating a level 1 transfuser), one can create targeted learning opportunities for each group of participants

Staged Entry Scenarios

Staged entry, where part of the team starts and others arrive later, creates opportunities to practice handover and leadership transition. It also allows team members, who would normally be in a supporting role, to do more of the initial assessment and resuscitation.

Distance Resuscitations

Simulating remote resuscitation (i.e the doctor is not present but must guide a team via the phone) can offer a unique hybrid of the blindfolded simulation and the staged entry scenarios (both discussed separately above). By setting the scenario is a remote centre (i.e. a nursing station without doctors) the non-Medical doctor team members can be in one room performing the physical simulation (i.e., hands-on resuscitation), while, in another room, physicians perform telephone simulation (i.e., they direct the resuscitation). Our experience is that these blended scenarios are well received by both the nonphysician group (who get to manage the entire resuscitation including procedures) and the physician group (who realize it requires as much "verbal dexterity" as "manual dexterity" to rescue a trauma victim). As outlined above, physicians frequently receive calls from distant centers but rarely practice "over the phone" resuscitations (where they cannot see the patient and must learn to rely upon others).

Measuring the Impact of Simulation

Lord Kelvin stated that if knowledge could not be expressed "in numbers," then it was "meager and unsatisfactory." This "Kelvin's Curse" [29] applies to debriefing (see next chapter) as well as to simulation design. Simulations are typically well received and increase participant confidence. However, given the complexity of resuscitation and the heterogeneity of this population, we may never conclusively prove that our simulations improve clinical outcome. Evidence-based tools, such as the Ottawa Global Rating Score [30], can help learners (and instructors) quantify where they started from and where they ended up. Ultimately, this may be the best way to determine whether the simulation was useful. Evaluation and assessment will be discussed further in Chap. 37.

Conclusions

Designing multidisciplinary simulation scenarios that are challenging and educational for all participants can be difficult. Creating discipline-specific objectives- following a needs' analysis- and encouraging input for all stakeholders helps form more robust scenarios. Use of a standard template helps create scripts that guide learners towards pre-determined and individualized educational goals. In this way, and by sticking to a few simple principles, one can create a safe and enjoyable learning environment for a truly multidisciplinary audience.

Key Points

- We need to do more simulation right, not just more simulation.
- Simulation is no panacea nor is it new in medical education.
- Simulation should be defined by technology, fidelity, and platform.
- Simulation is a technique, not a technology, and many strategies can be employed to increase realism.
- Simulation scenarios can be made to address each of Bloom's taxonomy (cognitive, psychomotor, attitudinal).
- The same scenarios can be easily individualized to many learners.
- Telephone simulation, blindfolded simulation, and handover simulation can add to the complexity and realism of simulation scenarios.
- Simulation development should include data collection and candid feedback.

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36 Constructive Debriefing for Trauma Team Education

Adam Cheng, Vincent J. Grant, and Naminder K. Sandhu

Introduction

The role of simulation-based education in training trauma teams and educating trauma team members is rapidly expanding [1–3]. As the key educational element of simulation-based education [2, 3], educator-guided debriefings are being increasingly studied and discussed in an effort to improve the effectiveness of the educational intervention. Debriefing, defined as a "facilitated or guided reflection in the cycle of experiential learning" [4], involves an active discourse between the debriefing facilitator and the various participants (e.g., learners), with the purposes of enhancing individual and team-based knowledge, skills, and performance. The overarching goal of post-event debriefings is to positively influence change in provider behavior, thus leading to improved patient care and outcomes [4–9].

There is an increasing body of literature examining how debriefing should be delivered to enhance educational outcomes from simulation-based education [10–20]. Video-assisted debriefing is often used by facilitators to promote after-action review by highlighting specific behaviors, both positive and negative, and using them as trigger points for discussion [10–13]. While the use of video-assisted debriefing is quite common among resource-rich simulation programs, studies of its use in simulation-based education have demonstrated mostly negligible effects for improving provider skills in a simulated environment [10–13]. The optimal method and context of use for video-assisted debriefing is still yet to be defined. Studies support the application of personalized debriefing (with a facilitator) over the use of multimedia debriefing (with no instructor present) [15, 16] or group-led debriefing (with no facilitator) [17]. Finally, the combination of debriefing with participants viewing expert-modeled performance of desired behaviors has shown promise in improving learner satisfaction, knowledge, and skills [18–20]. These studies help provide some insight into how post-simulation debriefing should ideally be conducted when training trauma teams.

Debriefing Structure and Method

Post-event debriefing, when applied to either simulation-based education or after a real patient case, is most efficiently and effectively performed when conducted in a systematic and structured fashion [6–9]. This section will review the overall structure of a debriefing event and discuss several methods that a facilitator can choose when reviewing the events of the case with the participating trauma teams.

Debriefing Structure

Structuring a post-event debriefing into various phases helps the facilitator manage time and content and also provides participants with a familiar flow when the same structure is consistently used within a single institution or program. The structure of a debriefing may vary depending on the preferences of the facilitator, their training in simulation-based education, and the amount of time available for the debriefing. Some of the potential phases of debriefing include a reaction phase, a descriptive phase, an analysis phase, and a summary phase (Table 36.1) [4–9, 21].

The reaction phase allows the facilitator to identify the initial thoughts and feelings of the participants and, ultimately, define learning objectives that are most important to the participants [4, 6–9]. In this phase, the facilitator asks

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Table 36.1 Debriefing structure

Phase	Description
Reaction	• Identify initial thoughts and feelings of participants • Define learning objectives that are important to participants • Emotional washout, unwrap mental mindset of participants • Facilitators track topics and plan how to address them
Description	• Serves to establish a shared understanding of the case • Solicit a brief summary of the case from a medical point of view and main issues • May be abbreviated if team members had clear shared understanding of the underlying diagnosis and key issues
Analysis	• Facilitators use various techniques to guide discussion and address learning and performance gaps • Integrate selected topics raised by participants • Multiple potential approaches – Debriefer prompts plus-delta list generation – Debriefer gives performance feedback – Debriefer facilitates a discussion using advocacy inquiry • Close performance gaps through discussion and/or teaching
Summary	• Allows learners to state take-home messages and how lessons learned apply to real-life clinical practice • Instructor may add final comments to augment essential elements

open-ended questions to provide participants the opportunity to vent their initial emotions related to the simulation, which may be feelings of frustration, fear, angst, confusion, appreciation, or elation over the event that has just taken place. Through this process, participants will also provide valuable information on their initial thoughts around the perceived care of the patient (both positive and negative). This step is vital to unwrapping the mental mindset of the participants (especially the emotional ones). If steps are not taken to allow the team members to share these emotions, they will be less likely to effectively reflect on their previous actions and, hence, unable to fully engage in interactive discussion during the remainder of the debriefing. Their initial thoughts are also key indicators of the areas that the participants want to review during the debriefing. Facilitators should carefully track these topics as they arise during the reaction phase and actively plan how and when they will address them during the analysis portion of the debriefing. As specific analysis and discussion of issues does not typically occur during this phase of the debriefing, the facilitator should consider summarizing the issues that have been brought forth by participants before proceeding to the next phase of debriefing.

The key purpose of the descriptive phase is to ensure that all team members have a shared collective understanding of the main details of the case, including the primary diagnosis and main clinical issues [21]. The facilitator typically asks one member of the team to summarize these details briefly in 1–2 sentences, followed by confirmation from other team members. In some cases, there are differing perspectives of the primary diagnosis or core issues. These should be clarified by the facilitator and/or the group before proceeding with analysis of specific behaviors. Failure to do so at this point in the debriefing may lead to confusion and/or misperceptions among some or all of the participants, thus increasing the risk of dissatisfaction or disengagement with the simulation debriefing at hand [21].

The bulk of debriefing is performed in the analysis phase [4, 6–9]. During this phase of debriefing, facilitators use various techniques to guide the team members toward identifying both positive and negative actions, as well as better understanding the rationale behind those actions and behaviors. By managing the flow and time available for discussion, the facilitator guides the group through issues that have been brought forth by participants while also covering the predefined learning objectives of the simulation scenario. Through reflective learning and feedback, the facilitator is able to promote the acquisition of new knowledge, skills, and attitudes, with the eventual goal of improving both individual and team performance in real patient care.

Once all of the performance issues have been identified, the final phase of debriefing typically involves a summary phase [4, 6–9, 21]. During this phase, a summary of the key take-home points is either provided directly by the facilitator or brought up and reviewed by the team. This ensures that the main learning points from the case are reinforced, with the hopes of positively influencing change in provider behavior for future trauma cases.

Debriefing Method

Several formats exist allowing the facilitator options when conducting the analysis portion of the debriefing. The method selected by the facilitator is most likely based on various factors: the time allotted for the debriefing event, the rationale evident behind the teams' actions during the scenario or event, the facilitators' comfort with using the selected method, the type of learning objective, and the level of insight/experience of the participants. The methods that will be reviewed here include advocacy inquiry (Debriefing with Good Judgement) [6–9], Plus Delta [4, 5], Directive Feedback, and Blended Methods of Debriefing [21].

Advocacy Inquiry

As a debriefing technique, advocacy inquiry (AI) attempts to uncover the "frame" or rationale behind a participant's behavior [7–9]. By uncovering the "frame" of an action, the facilitator better understands how to provide feedback for an action. This technique is particularly useful when the rationale behind an action is not clear or immediately apparent (to the facilitator or other team members). AI uses a series of factual statements to uncover the positive and negative performance issues without making assumptions as to the driving rationale behind these actions. The first statement is a clear, concise, and specific observation about an action or behavior that was seen or heard. The second is a short statement of appreciation or concern, reflecting the facilitator's point of view related the issue at hand. The third statement then asks the individual or team to share their point of view related to the topic at hand (Table 36.2). The responses from team member(s) will then guide further discussion from the team around the topic area, with a goal of consolidating positive performance and/or improving negative performance [7–9]. By promoting reflection on previous actions in this manner, the facilitator can effectively engage learners in discussion and even have insightful teams address performance issues and answer questions on their own. Although AI is a highly powerful method when done appropriately by a skilled facilitator, it often takes much time to practice and master this technique. That being said, facilitators should consider practicing this technique in lower-stakes learning environments before using it in environments where patient and/or learner safety are at higher risk.

Plus Delta

The plus-delta technique is another established technique where a facilitator guides a team to verbally produce two lists [4–6]. One list is the "plus"; the items that the team felt went particularly well during a case or simulation scenario. The second list is the "delta"; the items that the team felt could be improved upon for future performance. The advantages of this technique are that it is quick to learn and use and rapidly establishes a list of issues to frame further discussion.

Table 36.2 Advocacy inquiry [7–9]

Step	Possible statements/phrases
Observation	I noticed that…
	I saw that…
Facilitator point of view	At the time I was thinking…
	I was wondering…
Learner point of view	What were your thoughts at the time?
	How did you see it?

It is a particularly effective technique when there is very little time for debriefing [21]. Once the list of items are generated, specific issues may still require discussion, or at a minimum, the facilitator should provide some teaching to emphasize key take-home messages. The main disadvantage of the plus-delta method is that unless the individual items are further discussed in a reflective manner, the facilitator runs the risk of making inaccurate assumptions related to the underlying rationale driving specific actions and subsequently delivering the wrong teaching point [21]. For example, in a trauma resuscitation scenario, a nurse participant may comment that the team struggled executing the severe head injury protocol in a timely fashion. If the instructor makes the wrong assumption and assumes there was a knowledge deficit and subsequently starts teaching the severe head injury protocol, he/she may be missing out on the other potential causes for this performance deficit (e.g., errors in teamwork and communication).

Directive Feedback

Directive feedback is another technique when the facilitator provides teaching around a specific behavior or action. In its purest form, directive feedback is one directional (i.e., from teacher to learner) and does not involve discussion or reflective learning. This method is most suitable when the time available for debriefing is short, when the rationale behind a specific performance issue is clear and self-evident (to the facilitator and the group), or if the learners are inexperienced and/or have poor insight. This technique is particularly useful for clinical and technical skills, review of established guidelines or algorithms, and positive behaviors that one may want to reinforce. Similar to the plus-delta method, the main disadvantage is that the presumed rationale may be incorrect, with the consequence that the feedback provided targets the wrong objective.

Blended Methods

Experienced facilitators using the techniques described above have discovered that the use of one single debriefing method in isolation may not be optimally effective for all debriefing and learning environments. As such, some experts have advocated for a blended approach to debriefing while using various methods within a single debriefing event [21]. This allows for some flexibility based on the time allotted to debriefing, while still allowing the facilitator the ability to further uncover the rationale behind certain behaviors when there is uncertainty [21]. The blended approach allows for a more precise match of the specific learning needs of a team with the goals of the educator and should allow for more precise feedback in consolidating positive performance and/or improving negative performance.

Debriefing Real Trauma Teams

Advantages of Post-trauma Debriefing

Simulation provides fertile grounds for practice of effective resuscitation of critically ill patients and debriefing-generated learning on team process. Yet despite the growing evidence of the positive role of debriefing after surgical, anesthetic, or critical care-based simulation events [22–29], translating debriefing practice from the simulation setting to real-life events has been a challenge.

The concept of team-based debriefing after stressful events developed out of an intention to integrate profound personal experiences on the personal, emotional, and group level. Debriefing in healthcare moved into the spotlight in 1983, when Mitchell described a formal technique targeted toward emergency services and disaster response teams which aimed to protect and support the group exposed to a critical incident by minimizing the development of abnormal stress responses [30]. Originating as an early psychological intervention after critical incidents associated with psychological stress and trauma, the intention of debriefing has expanded and evolved with a focus on improvement of team process by way of an educational intervention.

Debriefing is becoming recognized as an increasingly important procedure in medical team training, although the literature on debriefing in-hospital trauma teams is sparse. Anecdotally, healthcare providers perceive a need for debriefing in the acute care setting. Individuals who have attended debriefing often rate the experience as "valuable," "helpful," and a "morale maintenance" intervention [31, 32]. As a performance enhancement tool, debriefing is beginning to receive significant attention from major international organizations in resuscitation such as the American Heart Association and International Liaison Committee on Resuscitation; in fact, they are endorsing debriefing for events such as cardiac arrest and identifying its impact on future performance and actual patient outcomes as an important area of research [33–36].

Review of Literature

A review of the literature shows that formalized debriefing has not yet become a standard practice in medical settings. In particular, surveys of emergency department staff in various countries have demonstrated a clear lack of formal debriefing practice after resuscitations despite a significant value placed on this process by healthcare providers. For example, pediatric emergency department physicians and nurses in Australia, the UK, and Canada have revealed that post-resuscitative debriefing is an uncommon practice although most find it helpful in reducing stress, thus identifying a perceived need but lack of a structured debriefing process [37–40].

Despite anecdotal evidence from surveys and short-term observational studies, stronger empirical evidence for the efficacy of debriefing as a stress-reduction intervention is lacking. In the small number of randomized control trials studying debriefing as a stress management intervention in various contexts (including nonmedical), early single-session debriefing of individuals exposed to traumatic experiences did not appear to reduce the risk of psychological distress or posttraumatic stress disorder [41]. It is difficult to translate this information to debriefing of trauma teams and does not speak to its efficacy as an educational intervention.

Studies focusing on debriefing benefits for team training are mostly extrapolated from the simulation education literature. Unfortunately, research and theory on debriefing has been spread across diverse disciplines, so it has been difficult to definitively ascertain debriefing effectiveness and how to enhance it. Yet the potential benefit to medical teams such as trauma teams is gradually being established. A meta-analysis from human factors literature done across a diverse body of published and unpublished research on team- and individual-level debriefs suggested that organizations can improve individual and team performance by approximately 20–25 % by using properly conducted debriefings [42].

In recent years, attempts at designing and implementing real-time debriefing programs have been made in acute care settings. For one, there is promising literature coming from the management of cardiac arrest in both adult and pediatric settings. Quantitative debriefing targeting pediatric cardiac arrest events has been shown to be feasible and useful for providers [43]. Quantitative debriefing refers to programs building upon classic qualitative debriefing (i.e., facilitated discussions of participant actions and thought processes) by the addition of actual quantitative patient information gathered from bedside CPR recording devices, patient monitors, and resuscitation records. The effect of debriefing techniques on real-life performance and patient outcomes is also fertile territory for the translation of current simulation-based knowledge and experience in debriefing. The use of playback of actual resuscitation events with targeted discussion of CPR performance is an effective way of improving rescuer knowledge and team performance in cardiac resuscitation, along with improved patient outcomes [35]. This work has broad applicability for improving trauma teamwork and the potential to improve outcomes from trauma events in general.

The challenge faced in assessing complex clinical team activities such as trauma resuscitation is developing validated metrics to assess competency. In terms of specific trauma team training tools, there is growing experience since the 1980s in performance review using videotapes as a technique to achieve behavioral changes and algorithm compliance, which has revealed some positive results. In fact, in some trauma centers, video analysis has become a standard quality assurance method [44–47]. Video recording trauma resuscitations and regular review has shown to improve trauma team leadership and the performance of residents in subsequent real-life resuscitations; overall, this method of debriefing seems to lead to reduced time in the emergency department prior to definitive care and improved delivery of key trauma resuscitation interventions. Videotape review based on trauma resuscitation guidelines has also been compared to verbal feedback and been shown to be more impactful in changing behavior. With such results, there is promising evidence that ongoing videotape review can be an important quality assurance adjunct, as improved algorithm compliance should be associated with improved patient care. Of course, videotaping of patient care requires overcoming substantial obstacles including medicolegal issues, confidentiality, and logistical and resource issues which restricts its use significantly [44–47].

Recommendations

There is growing evidence that supports the use of structured debriefing as an educational strategy to improve clinician knowledge and skill acquisition and implementation of those skills in practice. Debriefing of clinical teams after a life-threatening traumatic emergency can lead to improved process and patient-focused outcomes. However, the effect of debriefing on long-term patient outcomes is still uncertain. Furthermore, details of the most effective and pragmatic debriefing program for trauma teams are yet to be determined.

Given their potential efficacy and lessons learned from cardiac arrest, trauma videotape review, and simulation literature, debriefing should be a standard part of any team training intervention that incorporates, at minimum, a simulated team experience. In such cases, to promote alignment, the debriefing should involve the full team, focus on team improvements, and assess effectiveness with team-level performance measures.

Key Points

- Debriefing is an important component of simulation-based trauma team education.
- Post-event debriefing is most effective when conducted in a structured fashion.
- The method of debriefing should be tailored to the learning environment and context.
- Debriefing teams after real trauma events has potential to improve clinical outcomes in the future.

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Program Evaluation and Assessment of Learning

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Vicki R. LeBlanc and Walter Tavares

The use of simulation modalities for health professions education is both resource and time intensive. As such, there is an expectation to demonstrate that the program offered had the desired outcome, in terms of participant experiences, impact on learning or behavior of the participants, as well as in terms of desired institutional or patient-related outcomes. The goal of this chapter is to present a brief overview of program evaluation (outcomes-based and process-based). It will conclude with a more focused discussion of the assessment of learners, as this is a common foci of interest, not only for program evaluation but also for those interested in using simulation to determine their learners' level of abilities.

Program Evaluation

Because simulation-based education is time and resource intensive, there is often the need to demonstrate that the resources and time allotted to simulation-based courses or program are effective in meeting the desired learning objectives.

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Program evaluation is the systematic investigation of a program's worth [1]. It is the process of determining whether the program or course that has been designed works (or not) and whether (and how) in needs to be modified or improved. Program evaluation is the systematic collection, analysis, and use of information to answer questions about projects, policies, and programs, particularly about their effectiveness and efficiency.

There are several foci for program evaluation, including but not limited to:

- Assessment of the program's cost and efficiency.
- Assessment of program design.
- Assessment of the program's outcome (i.e., what it has actually achieved).
- Assessment of the program's impact on learning.
- Assessment of how the program is being implemented (i.e., is it being implemented according to plan?).

The two main approaches to program evaluation are outcomes-based evaluation and process-based evaluations. Program evaluation is often conceptualized as occurring at the end of the program (outcome-based), to determine whether the desired outcomes came to be. However, program evaluation can occur at several stages of a program (process-based), with the goal of determining how a program was implemented, as well as how and why it did—or did not—work as intended [2].

Outcomes-Based Program Evaluation

Outcomes-based program evaluation is aimed at answering the question of whether the program brings about the desired outcomes, generally defined by the course and learning objectives [2]. This is the type of program evaluation that is most familiar to health professions educators. There are several models to guide outcomes based program evaluation that have been used related to health professions education.

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The Kirkpatrick framework involves four levels designed as a sequence of ways to evaluate programs [3]. The four levels of the Kirkpatrick framework are:

Learner reactions: How the participants thought and felt about the program.
Learning: The increased in knowledge and/or skill, or the changes in attitudes that occurred as a result of the program.
Behavior: The transfer of the knowledge, skills, or attitudes to the work or clinical setting.
Results: The tangible results of the program in terms of costs, quality, or efficiency.

A similar framework, specifically applied to health professions, was proposed by Miller [4]. It is similar to the Kirkpatrick framework, in that there are several levels of assessment of skills and performance. The four levels of the Miller framework are:

Knows: Whether the student's knowledge has increased. This is considered the foundation of clinical skills, but is not sufficient to demonstrate changes in clinical skills and performance itself. It is generally measured with written exams.
Knows How: Whether a student can apply the knowledge learned. This is generally assessed using tests involving clinical problem solving.
Shows How: Whether the student can demonstrate a change in clinical skills and performance. This is generally assessed with behavioral examinations such as OSCEs and simulation modalities.
Does: Whether the learner's clinical skills and knowledge are improved during daily patient care. This is generally assessed with direct observation in real clinical contexts during patient care.

Program Evaluation Designs

In addition to determining the level of outcomes at which they are going to evaluate their program, educators also need to determine the design by which they will assess if there is desired improvement of knowledge, skills, performance or patient care has occurred.

The most straightforward method for conducting a program evaluation is to measure the impact of the program on the desired outcome measures after the program has been delivered. The limitation with this type of measure is that it does not provide any information regarding a learner's level of knowledge or performance before the course. As such, this approach does not allow the educator to determine whether a learner's current level of performance or knowledge is due to the program itself, due to baseline levels before the course, or other factors that occurred in parallel to the course.

One way to determine whether improvements occurred through the program is to use a pre–post design, where the outcome of interest is measured before the program, and then once again after the completion of the program. While this design allows educators to determine whether knowledge or skills improved from the baseline, it does not eliminate the possibility that the improvements were due to other factors that occurred in parallel to the program or to increase in performance merely due to repeated testing.

The next level of program evaluation design is to have an experimental design, with pre course and post course assessments, and a comparison group that is identical to the learners in the program, but does not receive the program. This design is considered superior for program evaluation, as it allows educators to separate out the influence of baseline ability and parallel events from those of the program itself. However, the limitation of this type of design is that it is resource and time intensive, and may create ethical concerns if the learners in the control group are withheld a particular learning opportunity. This last concern can be overcome with a crossover design, in which the students in the control group are offered the learning intervention after the post-course measures have been obtained.

In designing their outcomes based program evaluation, educators are often challenged by the difficulties in obtaining outcome measures at the level of "behavior" or "does," as well as with creating rigorous experimental designs. One question often asked is how strong is the need to prove that a program delivers the desired outcomes. In the case of a program that is already supported and established, in which other educators have shown that it works, it is generally acceptable to focus on learner feedback, pre- and post-course knowledge and skills assessments, mostly as a form of continuous monitoring of the quality of a program. If a program is novel, and potentially contested and challenged, educators will need to focus on behavioral or patient outcomes data, and will need to move towards a true experimental design with pre and post course measures and a comparison group. If one objective is to publish the results of the program evaluation in a peer-reviewed journal, the standards for publication have been consistently increasing over the years. A design with a control group or comparison training method, with validated measures of performance, is generally required for publication in peer-reviewed journals targeted to health professions educators.

Process-Based Program Evaluation

Process-based program evaluation, in addition to assessing the measurable outcomes of a program, is also geared towards fully understanding how a program was implemented as well as how and why the program did or did not have the desired outcomes [5]. This type of program evaluation looks beyond what a program is supposed to do, to evaluate how a program is being implemented and to determine whether the components critical to the success of the program are—or have been—implemented [2].

This type of program evaluation is an ongoing process in which multiple measures are used to evaluate how the program is being developed and delivered:

- How was the intervention developed, delivered and received?
- Are target populations being reached?
- Are people receiving the intended program?
- Are instructors, facilitators, technicians adequately prepared?
- What are the barriers to and facilitators of the development and delivery of the program?

In process-oriented program evaluation, the evaluator is not just interested in the outcomes of a program, but also in developing an understanding of the perspectives, experiences and expectations of all stakeholders, in order to determine whether the program was delivered in the manner it was intended.

The methodologies used in process oriented outcome measures include both quantitative and qualitative methods. They can include, among others, structured observations, questionnaires, semistructured interviews, focus groups, logs of meetings and program preparations, and analysis of course documents.

One model that can guide process-based program evaluation is the CIPP model, which looks at Context, Input, Process and Product [1]. Depending on the point at which the CIPP model is applied during program evaluation, it allows for formative questions at the beginning of the program, as well as a guide for evaluating the program's process and input throughout and at the end of the program:

- Context: What needs to be done? Were important needs addressed?
- Input: How should it be done? Was a defensible design employed?
- Process: Is it being done? Was the design well executed?
- Product: Is it succeeding? Did the effort succeed?

Assessment of Learning

Program evaluation may take on many forms; however, a common approach is to evaluate the impact a program has on learners. As an outcome measure, this may include the achievement of competencies, successful attainment of objectives, or changes in behavior. In each of these outcomes, there is a requirement to engage learners in a process of assessment at one of the levels of the Miller or Kirkpatrick framework discussed earlier in this chapter. As with any outcome measures, those engaging in the assessment of learning must ensure (at a minimum) the process demonstrates evidence of both reliability and validity. A comprehensive review of all stimulus and response formats (e.g., written, oral, computer based simulations etc.) is beyond the scope of this chapter. Therefore, we focus here on the complex process of performance based assessments, specifically as it relates to the direct observation, by one or more raters, of trainee performance in a simulation or work based setting.

The assessment of clinical performance is a complex process, involving broadly, four phases including (a) a stimulus, (b) learner behaviors, (c) direct observation by a rater/assessor and (d) rating or judgment transferred to a rating tool. The stimulus generally involves the development of a clinical challenge intended to elicit or expose a learner's ability as they relate to predetermined objectives or competencies. The learner then exhibits behaviors in response to the clinical challenge and a rater observes the performance, making reference to some performance expectations or standards along the way. This is then all transformed to some form of categorical judgment or rating regarding the candidate's ability and used to inform decisions regarding the learner's degree of competence, achievement of competencies, or objectives. Importantly, with the exception of phase 2 (learner behaviors) assessment developers have control of these facets, and the decisions and/or processes that assessment developers put in place have implications for both reliability and validity.

Reliability

Reliability serves as a type of quality index in assessments and refers to the ability to consistently differentiate between candidates [6, 7], with both consistency and differentiation being equally important. Consistency suggests that scores on a performance assessment would be relatively similar between raters (inter-rater reliability) within raters (intra-rater reliability), if tested a second time (test–retest reliability), across different stations (inter-station reliability), etc. On the other hand, differentiation suggests the assessment process is designed such that differences between candidates (if present) can be detected.

Reliability provides an indication of the ability to achieve this consistent differentiation but also an indication regarding the amount of error associated with the process [7, 8]. Error is present when a score is generated that is different than the "true" score. Error can be systematic (e.g., a rater is excessively or inappropriately stringent and scores are subsequently lower than the "true" score) or random (i.e., unpredictable). There is always a degree of measurement error associated with rater-based assessments and ideally, those sources are identified then mitigated where possible. Strategies to maximize reliability therefore involve both improving differentiation and minimizing error.

The question thus remains; how does one meaningfully maximize the ability to differentiate between candidates and minimize error? First, with regard to maximizing differentiation (i.e., the range of scores obtained in the assessment process), case development, the number of cases included and the rating tools used are all strategies that can be applied (just to name a few). Individual case development and the collection of cases used should ensure students are adequately challenged such that they are neither too difficult nor too simple. Rating scales with too few discrimination points (e.g., a dichotomous done/not done rating tool) may not allow for the necessary differentiation to support reliable assessments.

A second strategy to improve reliability involves minimizing the amount or degree of error associated with the process. Previous research exploring sources of error in performance-based assessments typically finds context specificity as the greatest source of error [9–13]. Context specificity refers to the counter intuitive finding that a candidate's performance on one case is a poor predictor of performance on another. For example, a candidate's clinical performance when presented with a patient experiencing an asthmatic exacerbation would not necessarily be predictive of performance when presented with a patient suffering from hemorrhagic shock. These findings suggest that in order to achieve the reliability expected of high stakes assessments, a number of cases (or samples) should be used. As the number of cases increase, the effect of context specificity (a significant source of error) is minimized and the closer one is to determining the individual's true performance ability [14]. Other sources of error (e.g., raters, rating tools) should also be considered and mitigated as much as possible, in order to further minimize error and improve reliability associated with performance based exams.

Validity

Validity refers to the degree of confidence one has in the inferences drawn based on the scores generated by an assessment process [15–17]. That is, validity refers to the plausibility, accuracy or appropriateness of a proposed interpretation (e.g., degree of competence), proposed use (e.g., certification vs. remediation) or use of test scores (e.g., advancement), and not the test itself. Validity refers to the degree to which the interpretation, for example, is supported by evidence [16, 18–20]. There are numerous implications associated with this conceptualization of validity. To begin with, validity is never actually achieved and there are different levels or degrees of evidence; some stronger than others. For example, demonstrating that a five station performance exam is perceived by experts, candidates and stakeholders to be a suitable measure of clinical performance (referred to a face validity) is a much weaker argument or source of evidence than having evidence of predictive validity in which performance on the five station exam actually predicts performance in future clinical settings (an admittedly difficult form of evidence to achieve) [21]. The stronger the arguments (i.e., empirical evidence in support of the interpretations) the more one can have confidence in and defend decisions made based on scores generated from an assessment process.

Unfortunately there are many threats to validity [9]. Broadly, these include poor reliability (discussed previously), lack of authenticity, construct underrepresentation or overrepresentation, and/or construct irrelevant variance [22]. These threats may be present in the stimuli (i.e., the clinical cases the candidates are presented with) or the response format (i.e., the rating tool used and/or raters themselves) [22, 23] When one or more of these threats are present and/or not reasonably mitigated, the extrapolations that one makes from the assessment context to future clinical contexts are weakened.

Focusing first on authenticity, where possible, the assessment format (i.e., stimuli) should match or align with the settings with which inferences and generalizations are eventually to be made [24]. Extrapolations from assessment contexts to future clinical contexts require less of a leap when the two settings are closely matched. For example, providing a multiple choice exam when the goal is to make inferences regarding a person's intravenous insertion skills is an inappropriate stimulus because it lacks authenticity and thus validity associated with the assessment process is threatened. Therefore, making inferences regarding intravenous skills based on scores generated on the written exam is difficult. However, using a highly realistic task trainer is far more authentic and therefore likely to be a stronger argument because it is a closer approximation to the future performance setting. Extending the example further, integrating the procedural skill into the broader context of assessment, prioritization, clinical reasoning, communication and resource considerations, offers additional authenticity. Finally, using a real patient in a real clinical environment with real contextual forces would require even less of a leap when extrapolating from assessment contexts to future clinical performance contexts. Therefore, when assessment at the "does" level (obviously the most authentic stimulus) is not feasible, simulations designed to replicate physical, conceptual and emotional realism should be employed to maximize validity [24]. This extends to ensuring cases involve full clinical encounters consistent with the health profession, as opposed to fragmented decontextualized skills (arguably less authentic).

A second and third threat to validity involves construct underrepresentation and overrepresentation [16]. In the context of the cases used (and assuming a performance examination at the "shows how" or "does" level), construct underrepresentation refers to undersampling of the domain of possible encounters. Hypothetically speaking, if there are 100 different skills or patient types in the domain of possible encounters, and the sampling strategy only includes 10 of each, the risk of construct underrepresentation is higher than if 20 of each were included. Of course, not all elements of the construct can be included in a given assessment process. Therefore, one must apply a reasonable sampling strategy using a structured blue print and appropriate framework. Construct overrepresentation would essentially be the opposite (albeit less common of a problem). That is, including content in a performance based assessment that was not representative of trauma care. One final threat that can be assigned to either construct underrepresentation or overrepresentation is in the representativeness of the sample. This refers to the degree to which the cases selected for an assessment process for example, represents the frequency of actual clinical encounters. This has significant implication for making predictions regarding future clinical performance. This is often addressed using a matrix of frequency and importance for a domain of possible encounters. Decisions need to be made regarding the distribution of cases across these two domains in addition to the sampling strategy issues described above.

Closely related is the concept of construct irrelevant variance, which refers to any systematic sources of error [8]. Construct overrepresentation for example, may be considered a type of construct irrelevant variance. Others sources may include flawed cases, poor rating scales, inappropriate rating items, various forms of rater biases (e.g., leniency and stringency, or restriction of range), inadequate sampling, poor case difficulty (either too easy or too difficult) etc [23]. Any of these may artificially lower or elevate scores (causing scores to inappropriately deviate from the "true score") thereby threatening validity claims.

With regard to the response format (i.e., direct observation measurement tools), both construct representation and construct irrelevant variance are applicable here as well. For instance, when developing or using a checklist or global rating scale, if the measurement tool does not adequately represent the construct by either missing important items or dimensions, or including items or dimensions that should not be included, then both construct underrepresentation and overrepresentation are possible. The measurement tools/response format used should demonstrate evidence of reliability and validity on their own but also in the context in which they are used to avoid threats to validity.

Summary

Simulation-based education requires significant time and resources. As such, educators are often required to provide evidence that the program accomplishes the desired goals, and that the performance measures obtained in this format are valid and reliable. In this light, the current chapter provided an overview of two related concepts. Program evaluation is conducted to determine whether a program led to the desired outcomes (outcomes-based evaluation) and to determine how a program was implanted (process-based evaluation). In a related goal, assessment of learning is conducted to determine a learner's level of knowledge or ability, and requires attention to ensuring the reliability and validity of the measures used.

Key Points

- It is important for educators to provide evidence that simulation programs accomplish the desired goals and that assessments made in the simulation context are sound.
- Program evaluation is used to determine whether a program led to the desired outcomes (outcomes-based), as well as how a program was implemented (process-based).
- Educators engaging in the assessment of learning must ensure that the process demonstrates evidence of both reliability and validity.

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Teaching Technical and Procedural Skills

38

Jameel Ali

Introduction

Excellence in technical skill performance is a major goal of medical training. Traditionally these skills were learned on live patients, allowing graded responsibility in the clinical setting [1, 2]. Several factors have driven changes in our teaching models. These factors include: reduction in training time, litigation threats, safety and economic issues [3–7].

Several alternatives have developed such as animal models [8, 9], fresh cadavers [10, 11], mechanical simulators [12, 13], virtual reality simulators [14], and distance learning [15, 16].

The Domains of Learning

Although technical skills could be taught in isolation, teachers should recognize the relevance of the established domains of learning in the acquisition of skills. These domains are the cognitive, psychomotor, and affective [17–20].

The Cognitive Domain

The cognitive domain focuses on the knowledge levels for skills learning. These levels (taxonomy) were initially characterized by Benjamin Bloom and others in the mid 1950s [18] and have since undergone many modifications [21] one of which is shown in Fig. 38.1. The lower levels merely require pure recall but the higher levels require such skills as comprehension, application, analysis, synthesis and evaluation—originally represented as a stepwise hierarchy but later considered as a group of critical thinking processes in parallel with each other.

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The Psychomotor Domain

The psychomotor domain focuses on the necessary neuromuscular and motor coordination aspects of acquiring a technical skill. One recognized taxonomy [22] of this domain describes the following five levels: Imitation—observing and repeating the action; Manipulation—responding to verbal instructions; Precision-practice—high level of accurate independent performance; Articulation—completes skill sequentially and consistently; Naturalization—demonstrates skill automatically without need for guidance. Further details on the psychomotor principles are discussed below.

The Affective Domain

The affective domain involves the emotional response and desire for satisfaction in good performance of a skill and an appreciation of its clinical significance (e.g., a lifesaving chest decompression procedure in a tension pneumothorax patient). A major part of this affective process is the motivation from the teacher (extrinsic motivation) as a positive role model. This motivation, which initially is extrinsic, ideally becomes intrinsic when the student internally values the skill and no longer requires the extrinsic motivation of the teacher to enhance his own learning. The process begins with "receiving" when, at the appropriate moment, the student consciously notes the concept being taught and follows this with an appropriate, hopefully positive, response. This leads to embracing the concept with an emotional valuing, followed by internalization and permanent change in the student's reaction to the concept or skill being taught (Fig. 38.2) This is known as Krathwohl's taxonomy of the affective domain [20]. A key element of this process is the recognition of "the teachable moment" when the student is most eager to observe and be receptive to the teacher's efforts. The effective teacher creates a receptive positive environment as a role model and stimulator of intrinsic motivation. This self-motivation then leads to development of the higher levels of the

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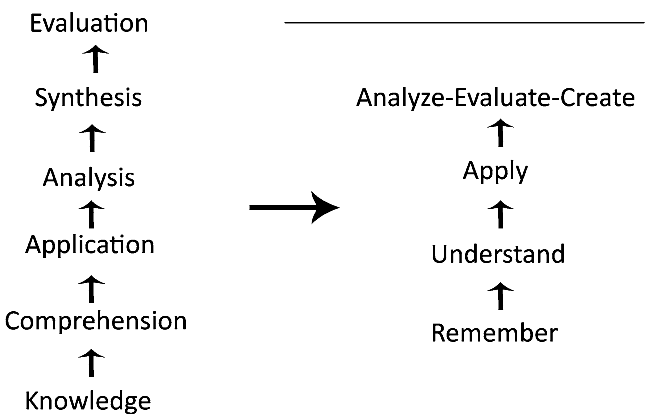

Fig. 38.1 Taxonomy of the cognitive domain. Bloom's original Taxonomy (*left*) with one of many modifications showing the higher levels in parallel as opposed to a stepwise hierarchy [18]

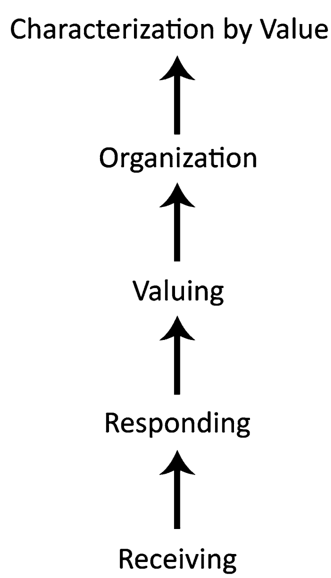

Fig. 38.2 Taxonomy of the affective domain. Krathwohl's stepwise description of the Affective Domain beginning with "receiving" [20]

affective domain such as "characterization by value." This progression along the affective domain is not accomplished by command but is stimulated by a highly motivated, sensitive teacher, acting as a role model.

All three domains of learning complement each other in the acquisition of technical skills. For instance, the cognitive aspect allows understanding of the anatomy, physiology, and indications for performing the skill; the psychomotor aspect focuses on the physical details of accomplishing the skill and performing it proficiently; while the affective component stimulates intrinsic motivation and emphasizes the value of the skill in the clinical management of a patient. As opposed to mere physical acquisition of a skill, the other domains lead to more complete learning. This may not make the skill easier to learn but the student, sensitized to the clinical significance of the skill through the affective component, is more likely to expend effort and energy to acquire a skill which may be difficult rather than abandon that skill merely because of its level of difficulty. Learning is often defined in terms of these three domains or "learning set" as the process of acquiring knowledge (cognitive), attitudes (affective), and skills (psychomotor). Teaching is then defined as the provision of opportunities for acquiring these three components of the learning set.

Principles of Psychomotor Skills Development

Understanding the sequential steps in psychomotor skills development is essential for the instructor to effectively plan the teaching, to evaluate and recognize progress, provide remediation and determine when the skill is achieved at the desired level. As indicated above, learning occurs when the student achieves new levels in the three domains. This requires a preliminary assessment of the student's level of achievement (e.g., Postgraduate Year (PGY)) that will guide further development in these three domains.

Several taxonomies of the psychomotor domain have been described [22, 23] with proposed methods for teaching technical skills. After reviewing these, George and Doto [24] have presented a stepwise approach to skills teaching. This has been adopted by the Advanced Trauma Life support program [25] which is the internationally recognized training program for trauma resuscitation and which includes a physician instructor training component. These sequential steps are:

Conceptualization

The learner is familiarized with the procedure as a whole, its indications, contraindications, risks, anatomic considerations, overall objectives; the focus is to review what is to be done in preparation for how it should be done in subsequent phases.

Visualization

The student observes the entire skill performed by an expert instructor. Audiovisuals may be used here for enhancement. This allows standardization of the procedure as well as review by students and other participating instructors.

Verbalization

A narrative of the individual motor steps and their specific sequence in the performance of the procedure is presented and then verbally repeated by the student.

Practice

Correct performance of a task immediately after instruction does not guarantee similar performance subsequently. This requires repetition enhanced by feedback. The number, frequency and duration of this practice have to be individualized to meet specific needs of the student. Practice over periods of years may be required to achieve clinical competence and is aided by supervision and feedback. Practice distributed over several teaching sessions involving separate tasks has been reported [26] to be superior to "massed" practice involving large blocks of time.

Feedback

The instructor's role is to be the expert guide who corrects and anticipates errors. With many surgical skills timeliness can mean the difference between life and death so our responsibility is to ensure accurate and rapid performance through timely feedback. Repeated errors without immediate correction lead to imprints of poor performance that are difficult to eradicate. This feedback should involve not only correction of errors but positive reinforcement for appropriately performed procedures. Further comments on feedback, in general, in the learning environment will follow.

Skills Mastery

After a period of practice with reinforcement and correction, the student is able to correctly and repeatedly perform the skill in a nonclinical environment (e.g., the skills lab).

Skills Autonomy

The real clinical situation presents challenges different from the nonclinical environment, with the affective component (fear, anxiety, inexperience, etc.) playing an important role. The students need to be supervised through their first real life experience in performing these procedures with appropriate feedback. Skills autonomy is achieved when the student repeatedly performs the procedure correctly in the real clinical environment. This emphasizes the importance of the teacher's role in ensuring safe practice of technical skills.

Relevance of the Steps of Psychomotor Skills Development

Students frequently have difficulty acquiring skills which we are trying to teach. Intuitively, an approach which allows analysis of the cause of poor performance should facilitate the remediation process. Awareness of the steps in psychomotor skills development serves as a diagnostic framework for identifying the cause of the student's deficiency and allows a rational strategy for remediation. The approach begins with identifying the level at which the student is experiencing difficulty starting with the Conceptualization step and sequentially examining all the other steps outlined above. For instance, if the student has a good grasp of the Conceptualization step (broad view, anatomic landmarks, etc.) then a search is made for possible deficiencies in the Visualization step (i.e., has the student ever seen the task performed? If not, the student should be provided the opportunity to visualize the skill before moving further along the skills development steps). Each step is approached in a similar manner and deficiencies corrected as they are identified.

At the Practice step, one of the most difficult deficiencies to remediate is habitual incorrect performance of a skill because the skill was taught and/or learned incorrectly and the student has no appreciation of the reason for the performance being considered poor. Unlearning of an incorrectly "imprinted" skill can be very challenging but if the student is willing to consider the change after agreeing that the performance is incorrect then one must begin at the Conceptualization level and patiently work forward through the different levels to achieve remediation.

Another difficulty which may be identified in the Practice step is physical neurosensory/neuromotor discoordination. This may require the expertise of a kinesiologist [27, 28] with the help of appropriate equipment to analyze fine motor movements and hopefully correct identified deficiencies.

Feedback

The recognized steps in formulating a teaching/learning experience with the student, including the teaching of surgical skills are: identify the changes in the "learning set" that are required; develop strategies for producing those changes and evaluate the change or lack thereof. Feedback is perhaps the most important component of this evaluative process and is crucial to successful teaching in general but particularly so in the teaching of surgical skills [29].

Feedback is a two-way process involving dialogue between instructor and student, beginning with clearly stated objectives after reviewing past learning. This should be viewed as a contract between student and teacher in which the gap between present skills and those to be learned is filled. The student must understand what needs to be achieved and at what stage, and be prepared to pursue these changes as outlined and guided by the instructor.

Feedback on the part of the instructor should be supportive with the intent to yield improvement based on comparison with a standard of performance that is clear to both student and instructor. It should be specific and, where possible, based on direct observation. In the context of skills teaching, the standard may be a readily accessible video demonstration of the skill so that the student may compare their performance with that on the video. Ideally, the instructor should be present to directly observe the student practice performance and provide feedback. Alternatively, the student performance may be videotaped and reviewed with the instructor. Feedback should, where possible, be immediate so that errors in performance can be corrected in a timely fashion.

Classification of Feedback

Feedback has been categorized as Formative and Summative. In the Formative category, feedback is provided as the skills are developed with corrections of errors and guidance on performance. This type of feedback is frequently conducted on an "ad hoc" basis, identifying issues and discussing them as soon as they are discovered.

The Summative feedback should be a planned session that requires preparation by both student and instructor. It is a set process which begins with asking the student for comments and questions on performance and self-evaluation to be followed by the instructor's comments. The completed task is discussed and an overall evaluation provided to the student.

Too often, students are presented with summative evaluations indicating poor performance without being provided previous opportunities to identify and correct poor performance as the skills are developed. The formative assessment should be spaced over time and the student provided with the option of "impromptu" access to the instructor for advice and guidance.

Each session should begin with a discussion of the performance, reinforcing and complimenting correct techniques as well as outlining deficiencies and means to correct them. The session should end with a summary and a defined plan for progressing further. This plan is reviewed at subsequent feedback sessions in order to judge the degree of progress.

Many feedback formats have been described, but the most frequently applied, primarily because it is the least complex, is the "Feedback Sandwich." In this model the instructor begins with identifying and complimenting the student's good performance followed by discussion of deficiencies and finally summary and overall plans for future performance. One frequent criticism of this model is the one way monologue from the instructor with limited active participation by the student [30]. Other models have been devised to address this deficiency but the "Sandwich" model could be modified and applied very effectively by beginning with asking the student to self-assess his/her performance followed by instructor input, as outlined, and seeking the student's opinion. The session should end on a positive, supportive but balanced note with defined plans for further development of the skills emphasizing the concept that expertise comes with continued practice and develops over years [31]

Effectiveness of the Paradigm Shift in Surgical Skills Training

Most residency training programs have adopted simulator models for surgical skills training and have established surgical skill centers which are accredited based on published standards [32]. These centers are very costly to establish and maintain [33]. It is therefore reasonable to assess their effectiveness. Many studies have demonstrated superior performance in knowledge retention and time to completion of suturing and knot tying [34], as well as transfer of skills from the laboratory to live models including the operating room [35] with positive impact on surgical outcome [36]. More large-scale studies are required for validation particularly in more senior learners and in live patients.

Key Points

- A switch in the paradigm for surgical skills training has resulted in widespread use of simulation-based models.
- Recognition of the contribution of all three domains of learning in skills teaching is important.
- Knowledge of the sequential steps in psychomotor skills learning should guide training and remediation.
- Appropriate feedback is crucial for successful teaching of technical skills.

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39 Multiple-Choice Review Questions

Sandy Widder and Lawrence M. Gillman

Chapter 1: The Genesis of Crew Resource Management: The NASA Experience

1. Crew resource management (CRM) was championed by the National Aeronautics and Space Administration (NASA) in order to?
   (a) Eliminate human error.
   (b) Fly more complex aircraft.
   (c) Improve crew experience.
   (d) A and B.
   (e) All of the above.
   Answer: D (see page 4)

2. Cognitive skills focus on which of the following?
   (a) Situational awareness.
   (b) Self-awareness.
   (c) Self-limitations.
   (d) Situational leadership.
   (e) Stress management.
   Answer: A (see page 4)

3. "Normalization of deviancy" does not occur as a result of?
   (a) Repetitive errors.
   (b) Unappreciated lapses.
   (c) Routine mistakes.
   (d) Redesign of plans.
   (e) Communication conflicts.
   Answer: D (see page 5)

4. The National Environmental (Outdoor) Leadership School (NOLS) classes incorporate?
   (a) Leadership skills.
   (b) Wilderness skills.
   (c) Outdoor ethics.
   (d) A and B.
   (e) All of the above.
   Answer: E (see page 5)

5. Surgical staff attitudes regarding teamwork consist of the following?
   (a) Low levels of teamwork, steep hierarchies, low fatigue.
   (b) High levels of teamwork, steep hierarchies, low fatigue.
   (c) High levels of teamwork, flattened hierarchies, high fatigue.
   (d) Low levels of teamwork, flattened hierarchies, low fatigue.
   (e) High levels of teamwork, steep hierarchies, high fatigue.
   Answer: B (see page 5)

Chapter 2: Evidence Supporting Crisis Resource Management Training

1. CRM is not based on which of the following principles?
   (a) Clear communication.
   (b) Resource utilization.
   (c) Situational awareness.
   (d) Leadership.
   (e) Effective management.
   Answer: E (see page 11)

2. CRM is regarded as a series of countermeasures with three lines of defense defined as?
   (a) Finding, measuring, and solving errors.
   (b) Avoiding, capturing, and mitigating errors.
   (c) Promoting, motivating, and rewarding teamwork.
   (d) Finding, capturing, and promoting errors.
   (e) Limiting stress, fatigue, and teamwork.
   Answer: B (see page 10)

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3. An effective leader is one who?
   (a) Flattens the hierarchy, micromanages, and makes firm decisions.
   (b) Emphasizes roles and responsibilities.
   (c) Flattens the hierarchy, delegates tasks, and makes firm decisions.
   (d) Promotes hard work and rewards appropriate behaviors.
   (e) Flattens the hierarchy, delegates tasks, and makes consensual decisions.
   Answer: C (see page 11)

4. Effective CRM training programs are based on which three crucial tenants?
   (a) Knowledge, practice, and wisdom.
   (b) Knowledge, practice, and teaching.
   (c) Knowledge, practice, and recurrence.
   (d) Knowledge, practice, and teamwork.
   (e) Knowledge, practice, and modeling.
   Answer: C (see page 11)

5. Simulation-based CRM training with focused debriefing has improved which of the following?
   (a) Team communication, work efforts, and resuscitation times.
   (b) Patient morbidity and mortality.
   (c) Attitudes toward simulation and effectiveness of teamwork.
   (d) Team communication, attitudes toward simulation, and promoting safety.
   (e) Team communication, avoiding errors, and promoting safety.
   Answer: D (see page 12)

Chapter 3: Leadership Theories, Skills, and Application

1. Trauma team leadership requires responsibility and which of the following?
   (a) The ability to make definitive decisions.
   (b) To see the entirety of the situation.
   (c) Authoritarian.
   (d) The ability to motivate others.
   (e) A, B, and D.
   (f) All of the above.
   Answer: E (see page 15)

2. Leadership skills are?
   (a) An innate gift that only a few individuals possess.
   (b) Can be learned from self-actualization and multiple perspectives.
   (c) Can be learned from a single experience.
   (d) Can be taught by role modeling.
   (e) A and D.
   Answer: D (see page 15)

3. Leadership supports collaboration of relationships, as management supports which of the following?
   (a) Fostering relationships.
   (b) Supporting logistics and functions of the team.
   (c) Providing resources.
   (d) None of the above.
   (e) All of the above.
   Answer: B (see page 16)

4. Effective and sustainable leadership begins with?
   (a) Self-awareness.
   (b) Self-assurance.
   (c) Confidence.
   (d) Emotional stability.
   (e) All of the above.
   Answer: E (see page 16)

5. The STOP technique involves?
   (a) Stopping, assessing the situation, taking a deep breath, observing, preparing one's self, and practicing what works.
   (b) Stopping, not acting immediately, tasking to others, observing, preparing one's self, and practicing what works.
   (c) Stopping, taking a deep breath, delegating tasks, preparing one's self, and practicing what works.
   (d) Stopping everyone, assessing the situation, delegating tasks, completing goals, and practicing what works.
   (e) None of the above.
   Answer: A (see page 18)

Chapter 4: Teamwork and Communication in Trauma

1. The most common reason for preventable error is?
   (a) Inability to make definitive decisions.
   (b) Lack of clearly defined roles.
   (c) Lack of clearly defined responsibilities.
   (d) Lack of teamwork.
   (e) Lack of delegation of tasks.
   Answer: D (see page 21)

2. Practical strategies to improve teamwork in a crisis situation include?
   (a) Climate and culture, establishing structure, creating and sharing a mental model, and cross-monitoring.
   (b) Culture change, flattening hierarchy, and mutual respect.

(c) Assigning roles, clear responsibilities, and delegating tasks.
(d) Monitoring workload, monitoring stress, and monitoring team dynamics.
(e) Practicing, debriefing, encouraging feedback, and repetition of tasks.
Answer: A (see page 22)

3. Practical strategies to improve communication in a crisis situation include?
(a) Citing names, clarity, and precision.
(b) Using mitigating language.
(c) Being assertive.
(d) Regular debriefings.
(e) Active listening.
Answer: E (see page 24)

4. The most common team failings include?
(a) Lack of accountability, lack of roles and responsibilities, and closed-loop communication.
(b) Lack of accountability, lack of check backs, and poor prioritization of tasks.
(c) Lack of corrective action, lack of usable information, and lack of cross-monitoring.
(d) Closed-loop communication, roles and responsibilities, and cross-monitoring.
(e) Lack of task prioritization and lack of closed-loop communication and accountability.
Answer: B (see page 22)

5. A shared mental model helps to?
(a) Form an ego-focused team.
(b) Form a task-focused team.
(c) Prioritize duties.
(d) Stabilize emotions.
(e) B, C, D.
(f) All of the above.
Answer: E (see page 25)

Chapter 5: Situational Awareness and Human Performance in Trauma

1. Situational awareness encompasses which of the following?
(a) Interpreting cues.
(b) Sharing of a mental model.
(c) Being aware of limited resources.
(d) All of the above.
(e) None of the above.
Answer: A (see page 27)

2. The three levels of situational awareness include?
(a) Focusing attention, sharing information, and finding a solution.
(b) Interpreting cues, understanding team dynamics, and awareness of conflict.
(c) Perception of stimuli, cognitive synthesis, and establishing a mental model.
(d) Scanning vigilance, reduction of fixation errors, and conflict resolution.
(e) Interpreting cues, team dynamics, and predicting the future.
Answer: C (see pages 27, 28, 29)

3. At low levels, stress can do which of the following?
(a) Promote team cohesiveness.
(b) Cause exhaustion and impair decision making.
(c) Stimulate attention and aid with task completion.
(d) Cause fixation errors.
(e) Aid with complex decisions.
Answer: C (see page 30)

4. Mitigating a crisis can occur by?
(a) Awareness of the behavior of others, modifying their behaviors, and practicing simulation.
(b) Awareness of our own behaviors, mandating checks, and practicing simulation.
(c) Awareness of our own behaviors, modifying our own behaviors, and realizing our own limits.
(d) Strong leadership.
(e) Awareness of team personalities, their strengths and limits, and modifying their behaviors.
Answer: B (see page 31)

5. Which of the following are true?
(a) Simulation has been shown to save lives.
(b) We tend to adopt herd-like behavior in a crisis.
(c) Animals, but not humans, can become motionless with extreme fear.
(d) Our brains function better with unique challenges than with familiar problems.
(e) There is no evidence to support safety messaging on airplanes.
Answer: B (see page 31)

Chapter 6: Paramedics and Nonmedical Personnel

1. Who is liable medicolegally for issues related to transport of care of the trauma patient?
(a) Sending physician.
(b) Receiving physician.
(c) Transport medicine physician.

(d) All of the above.
(e) None of the above.
Answer: D (see page 37)

2. Which drugs can a primary care paramedic not administer?
(a) Epinephrine.
(b) Ventolin.
(c) Succinylcholine.
(d) Nitroglycerin.
(e) All of the above.
Answer: C (see page 37)

3. Which of the following levels of EMS practitioner has the highest levels of experience, skills, and therapeutics at their disposal?
(a) Emergency medical responder.
(b) Primary care paramedic.
(c) Advanced care paramedic.
(d) Critical care paramedic.
(e) All of the above.
Answer: D (see page 36)

4. What are some of the training courses offered to paramedics to help create a framework for trauma care in the prehospital environment?
(a) Advanced Trauma Life Support (ATLS).
(b) Cardiopulmonary resuscitation (CPR).
(c) Pediatric Advanced Life Support (PALS).
(d) Surgical Trauma Acute Resuscitation Team Training (STARTT).
(e) International Trauma Life Support (ITLS).
Answer: E (see page 37)

5. The various skills and competencies for the different levels of paramedics in Canada are contained in which document?
(a) National Occupational Competency Profile.
(b) Caroline's textbook—*Emergency Care in the Street.*
(c) Individual College of Physician and Surgeon's Code of Conduct.
(d) Municipal bylaws.
(e) Provincial government.
Answer: A (see page 35)

Chapter 7: Transport Medicine

1. The EMS transportation decision to engage in "trauma bypass" with direct transport to a level 1 trauma center should be based upon what criteria?
(a) The CDC Guidelines of Field Triage for Injured Patients.
(b) Local trauma system protocols.
(c) Paramedic judgment and consultation with on line medical control.
(d) A and B.
(e) None of the above.
Answer: D (see page 39)

2. Which of the following is not a precipitant of secondary brain injury and not a concern for transport teams?
(a) Hyperchloremia.
(b) Hyperthermia.
(c) Hypoglycemia.
(d) Hypoxia.
(e) Hypercarbia.
Answer: A (see page 43)

3. The following regarding interfacility transport of the trauma patient is true?
(a) Ground transport is the most reliable and safest mode of transport.
(b) Fixed wing is the quickest mode of transport.
(c) Rotary wing is the most efficient mode of transport over long distances.
(d) Weather, distance, and geography can affect the rapidity and mode of transport.
(e) All of the above.
Answer: D (see page 41)

4. Before transporting patients, it is important to do which of the following?
(a) Securing IVs, endotracheal tubes, and Foley catheters.
(b) Completion of a transport safety checklist.
(c) Decompression of pneumothoraces.
(d) Bivalving any limb casts.
(e) All of the above.
Answer: E (see pages 42, 43)

5. Which of the following physical laws apply to aeromedical transport of the trauma patient?
(a) Pressure and volume are directly proportional.
(b) Rotary wing can fly above 10,000 ft.
(c) The pressure of a mixture of gases is equal to the sum of all of the constituent gases alone.
(d) Pressure and temperature are indirectly proportional.
(e) Even with injuries, we can compensate for mild hypoxia at altitude.
Answer: C (see page 44)

Chapter 8: Trauma Team Structure and Organization

1. The goals of a trauma team activation (TTA) include which of the following?
(a) Sharing prehospital information with the team.
(b) Allowing time to garner personal protective equipment.

(c) Familiarizing oneself with other team members.
(d) Getting necessary equipment and resources in the trauma bay.
(e) All of the above.
Answer: E (see page 48)

2. What are some of the roles of the trauma team leader (TTL)?
(a) Preparation of the team prior to patient arrival.
(b) Someone who possesses surgical skills.
(c) Protecting safety of trauma team members.
(d) A and C.
(e) All of the above.
Answer: D (see page 48)

3. When is it not appropriate to activate a TTA?
(a) Penetrating torso trauma.
(b) Hypertension in the periphery.
(c) GCS ≤ 8.
(d) Provider discretion.
(e) Transfusion of blood products en route.
Answer: B (see page 51)

4. Which of the following are not members of the trauma team in a major trauma center?
(a) Social worker.
(b) Orthopedic surgery.
(c) Respiratory therapy.
(d) Neurosurgery.
(e) Plastic surgery.
Answer: E (see page 48)

5. The ideal trauma bay should have which of the following characteristics?
(a) Spacious.
(b) Necessary equipment within close range.
(c) Fluorescent lighting.
(d) Located on the second hospital floor.
(e) Accommodate a CT scanner.
Answer: A (see page 51)

Chapter 9: Interprofessional Trauma Team Roles

1. The tension triangle does not consist of?
(a) Knowledge.
(b) Emotion.
(c) Self-awareness.
(d) Environment.
(e) None of the above.
Answer: C (see page 56)

2. Behaviors that promote "leader inclusiveness" include?
(a) Seeking team members' thoughts.
(b) Questioning team members.
(c) Promoting team hierarchy.
(d) Verbalizing acceptability of tasks performed.
(e) All of the above.
Answer: A (see page 56)

3. Nursing roles and responsibilities may include?
(a) Obtaining an initial history.
(b) Documenting interventions.
(c) Ensuring closed-loop communication.
(d) Administering medications.
(e) All of the above.
Answer: E (see pages 56, 57)

4. Respiratory therapist roles and responsibilities may include?
(a) Initiating and maintaining pulmonary mechanics.
(b) Administration of medications.
(c) Maintenance of situational awareness.
(d) Performs part of the primary trauma survey.
(e) All of the above.
Answer: E (see pages 57, 58, 59)

5. It is not important for each team member to?
(a) Regain situational awareness after performing a task.
(b) Cross-monitor other team members.
(c) Offer help when needed.
(d) Practice with guided debriefings.
(e) Practice outside of their comfort zone.
Answer: E (see pages 59, 60)

Chapter 10: The Trauma Bay Environment

1. The resuscitation area for a trauma can include the following except?
(a) Decontamination area.
(b) Triage area.
(c) Pharmacy.
(d) Radiology suite.
(e) Blood bank.
Answer: E (see page 62)

2. Ideal access to the resuscitation area should?
(a) Allow for efficient patient inflow.
(b) Minimize distance and travel to crucial areas.
(c) Be safe and secure.
(d) All of the above.
(e) None of the above.
Answer: D (see pages 61, 62)

3. Equipment and supplies in the trauma bay should not be?
   (a) Clearly labeled.
   (b) Conveniently organized.
   (c) Organized to minimize efficiency.
   (d) Organized to minimize wastage of actions.
   (e) Replenished regularly.
   Answer: C (see page 64)

4. Which of the following patients would be appropriate for admission to the Short Stay or Trauma Observation Unit?
   (a) A 92-year old woman with a small subarachnoid after a fall.
   (b) A 30-year old man with a few rib fractures and a comminuted tib-fib fracture after a motorcycle accident.
   (c) A 65-year old woman with a Grade 3 splenic laceration after being struck by a car.
   (d) A 52-year old man with a sternal fracture, retrosternal hematoma, and ECG changes after a motor vehicle accident.
   (e) A 21-year old man with peritonitis and hypotension after sustaining a gunshot wound to the abdomen.
   Answer: B (see page 65)

5. During resuscitation, it is not necessary to?
   (a) Have telephones readily available as communication tools.
   (b) Update all members of the trauma team with changes in conditions or plans.
   (c) Use pagers in times of mass casualties.
   (d) Have a backup communication system in times of crisis.
   (e) Have direct communication links between the trauma center and prehospital personnel.
   Answer: C (see page 63)

Chapter 11: Quality Improvement and Trauma Quality Indicators

1. Which is not a limitation concern when using current available ASCOT trauma quality indicators?
   (a) Poorly specified quality indicators may lower reliability and validity.
   (b) Indicators focus on hospital processes and outcomes as opposed to hospital care.
   (c) Indicators tend to measure outcomes and processes, but not structure.
   (d) There are not enough indicators that measure outcomes and processes for timely and effective dimensions of care.
   (e) All of the above.
   Answer: D (see pages 68, 69)

2. What is true with regard to Trauma Quality Improvement Program (TQIP)?
   (a) Benchmarking using indicators is not recommended due to varying case mix and acuity at different hospitals.
   (b) Has been criticized for using mortality-only measures.
   (c) By highlighting best practices of care, TQIP influences funding in pay-for-performance models.
   (d) TQIP uses composite measures scoring to take processes into account to predict mortality.
   (e) None of the above.
   Answer: C (see page 69)

3. What is a benefit of using plan-so-study-act (PDSA) as opposed to a traditional scientific method (randomized control trial)?
   (a) PDSA involves large teams to ensure stakeholder buy-in.
   (b) PDSA is done in real-world settings, making it more generalizable.
   (c) PDSA is quality improvement work and therefore does not require research ethics board approval.
   (d) PDSA cycling provides a method to incorporate improvement ideas as the project progresses.
   (e) PDSA does not involve the use of any statistical methods.
   Answer: D (see page 70)

Use this case for questions 4 and 5.

You are the trauma director in a tertiary care center and a case is brought to your attention where family complained of delayed surgery for a patient. This was a patient who frequently visits the ER with altered level of consciousness who did not receive a CT scan due to presumed intoxication. 5 h after admission to the ER, he was found with a blown pupil and received an urgent craniotomy for acute SDH.

4. What is an appropriate outcome measure to review to see if this is a system problem?
   (a) Cranial surgery < 24 h.
   (b) Head CT received within 2 h.
   (c) GCS score <13 and head CT received within 2 h.
   (d) Sub-/epidural hematoma receiving craniotomy within 4 h.
   (e) Time to initial neurological assessment.
   Answer: D (see page 68)

5. What is an appropriate process measure for this case?
   (a) Cranial surgery <24 h.
   (b) Head CT received within 2 h.
   (c) GCS score <13 and head CT received within 2 h.

(d) Sub-/epidural hematoma receiving craniotomy within 4 h.
(e) Time to initial neurological assessment.
Answer: C (see page 68)

Chapter 12: Putting It All Together: Quality Control in Trauma Team Training

1. Which of the following factors are considered to be important for the maintenance of "quality"?
   (a) Standards and an excellent leader.
   (b) Standards, review, and maintenance of standards.
   (c) Standards, review, esprit de corps, and organizational culture.
   (d) Standards, review, and resources.
   (e) Standards.
   Answer: C (see page 73)

2. Team-based work in trauma is essential due to?
   (a) Patients requiring complex care.
   (b) Increased specialization in health care.
   (c) Continuous quality improvement.
   (d) Policy emphasis on teamwork.
   (e) All of the above.
   Answer: E (see page 73)

3. Which of the following are considered to be part of Nancarrow's Interdisciplinary Competencies?
   (a) An identified leader who prioritizes, commands, and closes the loop on tasks accomplished.
   (b) Demonstration of team culture and an atmosphere of trust.
   (c) Quality patient-focused outcomes and using feedback for improvement.
   (d) B and C.
   (e) All of the above.
   Answer: D (see page 74)

4. Successful trauma teams display which of the following characteristics?
   (a) Dedication, loyalty, and persistence.
   (b) Commitment, competence, and communication.
   (c) Commitment, promotion of individual goals, and communication.
   (d) Common goals, competence, and command hierarchy.
   (e) Competence, performance, and promotion of individual goals.
   Answer: B (see page 74)

5. Which of the following factors could adversely affect trauma team dynamics?
   (a) Human factors, environmental factors, and equipment factors.
   (b) Policy and procedures.
   (c) Poor organizational management.
   (d) All of the above.
   (e) None of the above.
   Answer: D (see page 76)

Chapter 13: Trauma Resuscitation

1. The following mechanisms and characteristic injury patterns do not hold true?
   (a) Fall from a height>5 m is associated with spine, extremity, and solid organ injury.
   (b) Pedestrian traumas have a high incidence of solid organ injuries.
   (c) Blast injuries affect the middle ear, lungs, and hollow viscus.
   (d) Hunting and assault rifles cause significant cavitation and concomitant injuries due to the associated pressure wave.
   (e) Side impact collisions are associated with solid organ injury, extremity, and rib fractures.
   Answer: B (see page 82)

2. Clues to a difficult airway do not include?
   (a) Wide mouth.
   (b) Small chin.
   (c) Overbite.
   (d) Facial trauma.
   (e) Neck swelling.
   Answer: A (see page 84)

3. An ECG is not crucial as a primary survey adjunct to?
   (a) Correlate with troponins and rule out clinically significant cardiac contusions.
   (b) Rule out arrhythmias.
   (c) Rule out cardiac ischemia.
   (d) Rule out toxic ingestions.
   (e) Rule out clinically significant cardiac contusions.
   Answer: A (see page 86)

4. Resuscitation for a head injured patient should include the following parameters?
   (a) Mannitol 2–2.5 g/kg should be given if there is concern about brain swelling and possible herniation.
   (b) Keep $PaCO_2$ less than 35 mm Hg at all times in order to treat potential herniation.
   (c) Optimizing cerebral perfusion pressure.
   (d) Keeping patients euglycemic and treating hyperglycemia aggressively.
   (e) Cooling patients to preserve brain function.
   Answer: C (see page 87)

5. Which of the following is true?
   (a) Lateral compression fractures are associated with pubic rami and acetabular fractures and present with massive hemorrhage.
   (b) Open book fractures are associated with urethral or bladder injuries.
   (c) Pelvic binders are useful for maintaining hemodynamic stability in patients with vertical shear fractures.
   (d) Angiography is useful for controlling all forms of pelvic bleeding and should be considered in a hemodynamically unstable patient.
   (e) If FAST negative, and evidence of a pelvic fracture, consider angioembolization versus laparotomy for damage control.
   Answer: E (see pages 86, 87)

Chapter 14: Damage Control Resuscitation

1. Damage control resuscitation can be applied to which of the following statements?
   (a) Minimization of blood products, permissive hypotension, and sustained critical care.
   (b) Permissive hypertension, early transfer to the site needed to arrest hemorrhage, and sustained surgical care.
   (c) Minimization of crystalloid, permissive hypertension, and sustained critical care.
   (d) Minimization of crystalloid, early blood product transfusion, and abbreviated operative interventions.
   (e) Early blood product transfusion, early definitive operative interventions, and sustained critical care.
   Answer: D (see page 91)

2. Which of the following factors are important contributors to coagulopathy in the trauma patient?
   (a) Hypothermia, acidemia, and hypertension.
   (b) Blood products, shock, and tissue trauma.
   (c) Inflammation, blood products, and tissue trauma.
   (d) Shock, alkalosis, and blood products.
   (e) Hemodilution, hypothermia, and acidemia.
   Answer: E (see page 91)

3. Permissive hypotension is not acceptable in which of the following situations?
   (a) Subdural hemorrhage.
   (b) Elderly.
   (c) Prolonged transport times.
   (d) Delays in definitive interventions.
   (e) All of the above.
   Answer: E (see page 92)

4. Damage control surgery should be considered in patients with physiological derangements such as which of the following?
   (a) pH < 7.3.
   (b) Base deficit > 10.
   (c) Core temperature < 35 °C.
   (d) Fecal contamination.
   (e) Bleeding.
   Answer: C (see page 93)

5. Indications for catheter tamponade include which of the following?
   (a) Major superficial vascular injuries.
   (b) Small cardiac injuries.
   (c) Deep solid organ injuries.
   (d) All of the above.
   (e) None of the above.
   Answer: C (see page 94)

Chapter 15: Damage Control: From Principles to Practice

1. What are some of the intraoperative damage control principles that should be applied to a trauma patient?
   (a) Organs on a pedicle should not be sacrificed.
   (b) Liver and lung resections should be anatomical, and staplers used.
   (c) Pringle maneuver of the lung can be used to control bleeding.
   (d) The inferior vena cava should never be sacrificed.
   (e) None of the above.
   Answer: E (see page 102)

2. Ongoing damage control should occur in the intensive care unit, the following principles should be applied?
   (a) Serial blood work should be sent to monitor for further bleeding and coagulopathy.
   (b) If ongoing resuscitation is required, blood products should be administered in a 1:2:3 ratio.
   (c) Abdominal perfusion pressure is a reasonable endpoint for resuscitation.
   (d) Rewarming is usually not needed as most patients arrive fully resuscitated from the operating theater.
   (e) All of the above.
   Answer: A (see page 103)

3. Which statements apply to the management of blast injuries?
   (a) The provider should focus on the most obvious sites of injury.

(b) Control of bleeding with proximal arterial compression is advised as this will stop all forms of bleeding.
(c) Use large stacks of gauze to control bleeding.
(d) Tourniquets can be applied to exsanguinating extremities in damage control situations.
(e) Tourniquets should be removed within 8 h of being applied.

Answer: D (see page 104)

4. Which of the following statements does not apply to the management of burn injuries?
   (a) If EMS is unable to establish IV access in a timely manner, intraosseous access is contraindicated.
   (b) Once the patient is fully exposed, a clean dry dressing should be applied.
   (c) Burn patients at the extremes of age, with inhalational injuries, or burns to the hands, feet, or genital areas, should be referred and transported to a burn center.
   (d) The resuscitation endpoint for burn trauma patients is urine output.
   (e) None of the above.

   Answer: A (see pages 104, 105)

5. Which of the following statements apply to the management of a crush injury patient?
   (a) It is the third most common cause of death in earthquake victims.
   (b) For resuscitation, lactated Ringer's is the recommended crystalloid.
   (c) On-scene amputation should be performed to prevent complications of crush injuries.
   (d) A single prophylactic dose of antibiotics should be applied.
   (e) Complications of crush injuries include: acute kidney injury, rhabdomyolysis, and compartment syndrome.

   Answer: E (see pages 106, 107)

Chapter 16: Trauma Team Decision Making

1. The choice of transfer destination is true in which of the following?
   (a) Shock patients responding to resuscitation should be taken to the operating theater.
   (b) If the hemodynamic status of a patient is unclear, a period of watchful waiting may be warranted.
   (c) Patients with compensated shock can safely proceed to the CT scanner.
   (d) Angiography may be used in patients with surgically accessible injuries.
   (e) Hemodynamically unstable patients need to have a diagnosis before deciding on a final decision for transfer.

   Answer: B (see pages 111, 112)

2. Which of the following statements is false?
   (a) In a hemodynamically unstable patient with thoracoabdominal trauma, a thoracotomy should be performed first.
   (b) Diagnostic adjuncts can be used intraoperatively in order to determine the cause of shock in a hemodynamically unstable patient.
   (c) In the operating room (OR), the TTL should ensure the team is aware of the risks, expected operative strategies, and anticipated equipment needs.
   (d) The OR should be part of the trauma team activation call in order to facilitate capacity and transfer.
   (e) Surgical capabilities in the resuscitation room can improve outcomes in some hemodynamically unstable trauma patients.

   Answer: A (see page 113)

3. Which of the following statements is true regarding transfer of the trauma patient?
   (a) The two logistical challenges regarding transfers include: arranging the transport and documenting a transfer summary.
   (b) Incomplete communication can delay transfer of a patient.
   (c) Physicians should rely on EMS familiarity with local and regional trauma expertise to help facilitate transfers.
   (d) Transfers should occur in an expeditious manner to the nearest available site.
   (e) Checklists do not improve information transfer in interfacility transfers.

   Answer: B (see page 114)

4. Which of the following regarding predictive scores is false?
   (a) Help transform raw data in to clinically relevant information to help with decision making in the care of trauma patients.
   (b) The TACH score can be used to predict outcomes.
   (c) The ABC score consists of: trauma mechanism, heart rate, blood pressure, and FAST ultrasound.
   (d) Predictive scores can help trauma teams make evidence-based decisions around patient care.
   (e) None of the above.

   Answer: B (see page 115)

5. Situational awareness is defined as?
   (a) The perception of elements in the environment.
   (b) The comprehension of the meaning of environmental elements.
   (c) The projection of these elements' status in the future.
   (d) All of the above.
   (e) None of the above.

   Answer: D (see page 117)

Chapter 17: Emergency Critical Care Procedures

1. When performing emergency procedures, it is important to?
   (a) Ensure the health and safety of each team member.
   (b) Perform procedures prophylactically to decrease the risk of patient demise.
   (c) Perform pre-procedure debriefings.
   (d) See one, do one, and teach one.
   (e) Ensure that they are controlled, organized, safe, and incorporate unsterile techniques.
   Answer: A (see page 121)

2. There are three main approaches to cricothyroidotomy, they are?
   (a) Needle cricothyroidotomy, open tracheostomy, and surgical cricothyroidotomy.
   (b) Surgical cricothyroidotomy, surgical tracheostomy, and surgical thyroidectomy.
   (c) Surgical cricothyroidotomy, percutaneous cricothyroidotomy, and needle cricothyroidotomy.
   (d) Needle cricothyroidotomy, percutaneous thyroidectomy, and surgical cricothyroidotomy.
   (e) None of the above.
   Answer: C (see page 122)

3. Relative contraindications to tube thoracostomy do not include?
   (a) Coagulopathy.
   (b) Bullae.
   (c) Pneumonia.
   (d) Adhesions.
   (e) Loculated effusions.
   Answer: C (see page 122)

4. Indications for central venous access do not include?
   (a) Hypoalimentation.
   (b) Hemodialysis.
   (c) Placement of transvenous cardiac pacemakers.
   (d) Repetitive blood sampling.
   (e) High volume/flow resuscitation.
   Answer: A (see page 124)

5. It is appropriate to perform a resuscitative thoracotomy if?
   (a) There are no signs of life.
   (b) Penetrating cardiac trauma with witnessed cardiac arrest within 20 min of presenting to a trauma center.
   (c) Blunt trauma who is unresponsive with hypotension.
   (d) Massive hemorrhage and need for vascular control.
   (e) It is done in a teaching center.
   Answer: D (see pages 126, 127)

Chapter 18: Trauma in the Pediatric Patient

1. Multiple injuries are the norm in pediatric patients. What factors play a role?
   (a) Small body size.
   (b) Compliance of the chest wall.
   (c) Lack of protection of the liver and spleen.
   (d) All of the above.
   (e) None of the above.
   Answer: D (see page 133)

2. Children have a higher incidence of intracranial hematomas than adult patients.
   (a) True.
   (b) False.
   Answer: B (see page 134)

3. Crisis resource management involves principles of interpersonal interactions and behaviors that contribute to poor team function during crisis management.
   (a) True.
   (b) False.
   Answer: B (see page 140)

4. Crisis resource management involves key principles including?
   (a) Leadership.
   (b) Resource utilization.
   (c) Teamwork.
   (d) All of the above.
   (e) None of the above.
   Answer: D (see page 140)

5. Collateral history from the parents of a traumatized child is an effective and reliable means of obtaining relevant information of the traumatic event.
   (a) True.
   (b) False.
   Answer: B (see page 135)

Chapter 19: Trauma in Pregnancy

1. Shock in a pregnant trauma patient will always manifest as?
   (a) An increased heart rate and decreased blood pressure.
   (b) Increased heart rate only.
   (c) Alterations in blood pressure only.
   (d) Abdominal pain.
   (e) An abnormal fetal heart rate pattern.
   Answer: E (see page 146)

2. Which of the following statements is false?
   (a) Uteroplacental blood flow accounts for 20 % of the cardiac output in the third trimester.
   (b) Placental vasculature is only minimally responsive to exogenous catecholamines.
   (c) In a perimortem cesarean delivery, maternal chest compressions should be continued while the infant is surgically delivered.
   (d) A pregnant patient with a symphysis fundal height of 28 cm likely has a gestational age of ≥24 weeks.
   (e) All of the above.
   Answer: B (see page 146)

3. Radiation exposure to the fetus is?
   (a) Not a consideration as the mother's care supersedes that of the unborn fetus.
   (b) Not associated with an increased risk of fetal anomalies if < 10 rad.
   (c) Can be either calculated by a medical physicist or measured by a dosimeter.
   (d) The same for a CT head as for a CT abdomen.
   (e) None of the above.
   Answer: C (see page 150)

4. Which of the following statements is true?
   (a) Kleihauer-Betke (KB) testing should be performed on all pregnant trauma patients.
   (b) Anti-D immune globulin should be administered to all pregnant trauma patients.
   (c) All pregnant trauma patients require 24 h of cardiotocographic monitoring prior to discharge.
   (d) Small amount of vaginal bleeding is normal for a pregnant trauma patient.
   (e) All of the above.
   Answer: A (see page 147)

5. The role of the obstetrician as part of the trauma team is to?
   (a) Perform a cesarean section at the direction of the TTL.
   (b) Admit any pregnant trauma patients to their service.
   (c) Perform the vaginal exam only.
   (d) Monitor the fetus for any abnormalities.
   (e) Provide integrated comprehensive care in coordination and cooperation with the trauma team.
   Answer: E (see page 152)

Chapter 20: Medical Comorbidities and Trauma

1. The elderly population is expected to make up 20 % of the total US population by what year?
   (a) 2100.
   (b) 2015.
   (c) 2050.
   (d) 2150.
   (e) 2035.
   Answer: C (see page 157)

2. Elderly patients have better outcomes when treated at level I versus level III trauma centers with less resources, true or false?
   (a) True.
   (b) False.
   Answer: B (see page 161)

3. Which of the following treatment modalities are contraindicated in older patients?
   (a) Damage control laparotomy.
   (b) Nonoperative management of blunt splenic injury.
   (c) Intensive invasive monitoring after injury.
   (d) Craniotomy for head trauma.
   (e) None of the above.
   Answer: E (see pages 159, 160)

4. Multimorbidity or the presence of multiple medical comorbidities in the same patient is present in what proportion of 19- and 80-year-old patients, respectively?
   (a) 2 % and 35 %.
   (b) 1 % and 55 %.
   (c) 10 % and 80 %.
   (d) 35 % and 60 %.
   (e) 20 % and 70 %.
   Answer: C (see page 157)

5. Obesity rates among males over 75 years of age have changed how over the last decade?
   (a) Decreased by 5 %.
   (b) Stayed constant.
   (c) Increased by 33 %.
   (d) Doubled.
   (e) Tripled.
   Answer: D (see page 157)

Chapter 21: Basic Trauma Ultrasound

1. Basic (classic) FAST consists of scanning four sites, these are?
   (a) Pericardial, retroperitoneum, pulmonary, and pelvis.
   (b) Pericardial, pulmonary, perihepatic, and perisplenic.
   (c) Pericardial, perihepatic, perisplenic, and pelvis.
   (d) Pericardial, retroperitoneum, perisplenic, and perihepatic.
   (e) All of the above.
   Answer: C (see page 167)

2. Which of the following statements are true?
   (a) FAST exam is performed using a high-frequency curvilinear probe.

(b) Dense tissue appears dark, while non-echogenic tissue appears white.
(c) The exam can be made technically difficult by the presence of fluid.
(d) Dense tissue appears white, while non-echogenic tissue appears dark.
(e) A direct relationship exists between the depth of penetration and resolution of the scan.
Answer: D (see page 167)

3. The Sonographic Outcomes Assessment Program (SOAP) trial demonstrated?
(a) That there were no benefits to the use of FAST in trauma patients.
(b) A 33 % reduced time to operative intervention with use of FAST.
(c) An increase in the number of false positive diagnoses in trauma patients.
(d) A 27 % decrease in hospital length of stay.
(e) B and D.
(f) None of the above.
Answer: D (see page 171)

4. The advantages of FAST use in trauma include?
(a) Diagnosis of free intra-abdominal fluid.
(b) Portable.
(c) Rapid.
(d) Repeatable.
(e) All of the above.
Answer: E (see page 171)

5. Which of the follow statements about FAST are FALSE?
(a) Poor tool for detecting hollow viscus injury.
(b) False-negative rates are higher in blunt versus penetrating trauma.
(c) Small amounts of physiological fluid can be detected, which does not necessarily equate to injuries in the trauma patient.
(d) Operator abilities can influence diagnostic sensitivity of FAST.
(e) The goal of FAST should be the identification of free fluid in the abdomen.
Answer: B (see pages 171, 172)

Chapter 22: Trauma Ultrasound: Beyond the Fast Examination

1. Which of the following is true regarding the diagnosis of a pneumothorax?
(a) Back and forth movement of the visceral and parietal pleura is present.
(b) Sliding sign can be seen using Z-mode.
(c) Ultrasound shows loss of the sliding lung sign.
(d) Air from the pneumothorax blocks the ability to image the parietal pleura.
(e) The barcode sign is the presence of parallel vertical lines and can indicate the presence of a pneumothorax.
Answer: C (see page 178)

2. Which of the following statements is false?
(a) A view of the inferior vena cava (IVC) with the cardiac ultrasound during a FAST exam can help determine volume status of the trauma patient.
(b) If the IVC collapses with normal respiration, it is an indicator of low intravascular volume.
(c) A dilated, non-varying IVC greater than 2 cm is an indicator of fluid overload.
(d) As little as 250 cc blood volume loss in a trauma patient can be detected by IVC variability measurement.
(e) Positive pressure ventilation can mask IVC variability.
Answer: D (see page 179)

3. Which of the following regarding the use of ultrasound in musculoskeletal evaluations is true?
(a) Can be used to determine the integrity of the bony cortex and whether a fracture is present.
(b) Bony cortex is seen as a dark, typically linear, line.
(c) A long bone should be imaged in the longitudinal and circumferential axis.
(d) In the short axis, a long bone such as the humerus will appear flat.
(e) Growth plates are never mistaken for bony fractures.
Answer: A (see page 179)

4. Ultrasound can be used in head trauma to do which of the following?
(a) Visualize intracranial hemorrhage.
(b) Estimate intracranial pressures (ICP) by visualizing brain ventricles.
(c) Measure optic nerve sheath diameter (ONSD) through the temporal bone.
(d) Measure ONSD to estimate ICP.
(e) Visualize the optic nerve at its point of penetration into the brain.
Answer: D (see page 181)

5. With regard to contrast-enhanced ultrasound?
(a) Enhances sensitivity of detection of hollow organ injuries.
(b) Has been approved worldwide for use in humans.
(c) Is as good as a CT scan in the detection of injuries.
(d) Areas of hematoma or areas of inactive perfusion are lit up by the contrast.
(e) Active bleeding can be denoted by pooling of the contrast.
Answer: E (see page 182)

Chapter 23: Telemedicine and Future Innovations

1. Which of the following statements does not currently apply to telemedicine?
   (a) Use of electronic signals to transfer medical data.
   (b) Increasing access to health care.
   (c) A client obtains advice via haptics.
   (d) Email is a common method of store and forward interaction.
   (e) In emergency cases, it can deliver rapid response times.
   Answer: C (see pages 187, 188)

2. Telemedicine interactions are broadly classified as?
   (a) "Store and forward" and "synchronous".
   (b) Prerecorded and real time.
   (c) "Store and forward" and prerecorded.
   (d) A and B.
   (e) A, B, and C.
   Answer: D (see page 187)

3. "Telepresence" describes which of the following?
   (a) Ability of providers to interact in real time with telecommunication equipment.
   (b) Ability to offer immediate feedback and assistance.
   (c) Ability to bridge experience gaps to trauma care.
   (d) Ability to bridge access and resource gaps to trauma care.
   (e) All of the above.
   Answer: E (see page 188)

4. Which of the following statements is false supporting the use of telemedicine?
   (a) Improves trauma care but delays triage and transport.
   (b) Improving trauma care provided at lower cost.
   (c) Decreases unnecessary transfers.
   (d) Supported by both health-care staff and patients.
   (e) Ability to fill in trauma knowledge gaps.
   Answer: A (see page 189)

5. Which of the following factors are necessary in order to develop a telemedicine system?
   (a) A comprehensive business plan.
   (b) Ensuring security of patient data.
   (c) Integration of staff into any engineering or technical changes.
   (d) Account for linguistic and literacy differences.
   (e) All of the above.
   Answer: E (see page 190)

Chapter 24: Imaging in the Stable Trauma Patient

1. Which of the following patients should not proceed to the CT scanner?
   (a) A patient with a positive FAST.
   (b) A patient with a suspected pelvic fracture.
   (c) A patient that is hemodynamically unstable.
   (d) A patient that is a transient responder.
   (e) A patient that is intubated.
   Answer: C (see page 196)

2. Which imaging studies must be performed and reviewed prior to a stable trauma patient leaving the trauma bay?
   (a) CXR and FAST.
   (b) Extremity X-rays and FAST.
   (c) CXR and lateral C-spine X-ray.
   (d) Lateral C-spine X-ray and FAST.
   (e) Abdominal X-rays and FAST.
   Answer: A (see page 197)

3. Which of the following statements is false?
   (a) The FAST exam is a helpful adjunct in unstable trauma patients.
   (b) All patients with a positive FAST exam should be taken emergently to the operating room.
   (c) The FAST exam includes three abdominal views and a pericardial view.
   (d) The FAST exam should be called for and performed early in trauma resuscitation.
   (e) The FAST exam can be repeated several times during a trauma resuscitation.
   Answer: B (see page 195)

4. A trauma "pan-scan" includes CT imaging of which of the following body parts?
   (a) Head, C-spine, chest, and lower extremities.
   (b) Head, face, C-spine, abdomen, and pelvis.
   (c) Head, C-spine, abdomen, pelvis, and lower extremities.
   (d) Head, C-spine, chest, abdomen, and pelvis.
   (e) Head, t-spine, chest, abdomen, and pelvis.
   Answer: D (see page 196)

5. Which of the following statements about planning care in the stable trauma patient is true?
   (a) Early and frequent communication with the definitive care unit is a crucial step.
   (b) Stable trauma patients should be kept in the trauma bay as long as possible.
   (c) The radiology department does not need to be notified as trauma scans are urgent.

(d) As many CT scans as possible should be completed prior to transferring the patient to the lead trauma hospital.
(e) If a patient is unstable, the scoop and run approach is most appropriate; notes and documentation can be completed later.
Answer: A (see page 198)

Chapter 25: Disaster Medicine

1. A disaster is defined as an event that causes disruption:
   (a) With multiple casualties and/or that involves a wide area.
   (b) Which exceeds the ability of the affected community to cope using its own resources.
   (c) Requires the collaborations of several agencies.
   (d) Requires several resources.
   (e) All of the above.
   Answer: B (see page 203)

2. The Incident Command System (ICS):
   (a) Is a modular organization used for all disasters.
   (b) Is a framework used to respond in case of international disaster.
   (c) Is established to solve tactics issues.
   (d) Is a framework established in case of a CBRN (chemical, biologic, radiological, and nuclear) event.
   (e) None of the above.
   Answer: A (see page 205)

3. An incident commander (IC) is in charge for all the?
   (a) Activities on the scene of the disaster event.
   (b) Operational activities.
   (c) Health-care activities.
   (d) Organization of necessary resources.
   (e) Activities regarding the incident.
   Answer: E (see page 205)

4. The purpose of triage in disaster event is?
   (a) To classify casualties to provide quick transportation for critical patient.
   (b) To identify patients that require surgical treatment.
   (c) To sort the casualties in agreement with the severity of the injuries.
   (d) To identify patients that required specialized treatment.
   (e) To transport patients to the appropriate care sites.
   Answer: C (see page 206)

5. In case of disaster, the incident action plan (IAP) establishes?
   (a) Goals, times, activities, and the response strategy.
   (b) Drafts mission, roles, and responsibilities of every responder.
   (c) Standard operating procedure during disaster.
   (d) Guidelines regarding the treatment of the casualties.
   (e) Resources, capacity, and delegation of tasks.
   Answer: A (see page 205)

Chapter 26: The Multicasualty Trauma

1. Challenges while managing a mass casualty trauma include which of the following?
   (a) Hostile environments.
   (b) Triaging patients.
   (c) First responders placing their own lives at risk.
   (d) Resource allocation.
   (e) All of the above.
   Answer: E (see page 209)

2. Which of the following are true of the triage process?
   (a) Primary triage is performed by surgeons, anesthesiologists, or emergency physicians.
   (b) Tertiary triage is performed by paramedics or first-level responders at the scene of the event.
   (c) Secondary triage is performed at the accepting facility typically by the most experienced health-care professional.
   (d) All of the above.
   (e) None of the above.
   Answer: C (see page 210)

3. Which of the following facts concerning triage is true?
   (a) Patients should be tagged with a triage wristband.
   (b) A less than 5 % over triage rate and less than 50 % under triage rate is acceptable.
   (c) Overtriage can lead to inappropriate utilization of limited resources.
   (d) The triage officer should be someone who has minimal responsibilities and is readily available.
   (e) Triage decisions can follow a protocol to make them less emotionally challenging.
   Answer: C (see page 210)

4. The simple triage and rapid treatment system allows patients to be classified as a color to help with their triage, which of the following is not true?
   (a) Black—deceased.
   (b) Red—immediate care.
   (c) Yellow—delayed care.
   (d) Green—ambulatory care.
   (e) White—imminent death.
   Answer: E (see page 212)

5. Preparation for a mass casualty trauma includes?
   (a) Having a clear inventory and surge capacity plan in place.
   (b) Regular updating of contact information, testing, and analysis of responses to simulated disaster alerts.
   (c) Simulation of mass casualty traumas.
   (d) All of the above.
   (e) None of the above.
   Answer: D (see page 215)

Chapter 27: Critical Incident Team Dynamics and Logistics

1. Crew resource management is characterized by?
   (a) A culture of safety.
   (b) Unequal resources.
   (c) Siloing of capabilities.
   (d) Operational security.
   (e) A culture of blame.
   Answer: A (see page 217)

2. Which of the following is not a characteristic of a crisis?
   (a) Confusion.
   (b) Chaos.
   (c) Surety.
   (d) Time sensitivity.
   (e) Human elements.
   Answer: C (see page 218)

3. Which of the following best describes the feature of highly functioning teams that have repetitively worked well together and have undergone performance improvement as a unit?
   (a) Self-actualization.
   (b) Dynamic throughput.
   (c) Performance gating.
   (d) Transactive memory.
   (e) Domain matching.
   Answer: D (see page 220)

4. Sleep deprivation is associated of all of the following except:
   (a) Cardiovascular disease.
   (b) Loss of impulse control.
   (c) Impaired judgment.
   (d) Reduced reflex time.
   (e) Reduced endurance.
   Answer: D (see page 223)

5. Which of the following characterizes command as opposed to control?
   (a) Compelled compliance.
   (b) Implied influence.
   (c) Persuasive power.
   (d) Delegated authority.
   (e) Leading by example.
   Answer: A (see page 218)

Chapter 28: Terrorism and Urban Trauma

1. In urban trauma, events that require SWAT team activation, paramedics, or physicians embedded in SWAT teams are:
   (a) Routinely equipped with firearms just like other SWAT operators.
   (b) Required to remain behind the outer perimeter to provide safe care.
   (c) Participate in room clearing and explosive breaching events.
   (d) Utilize tactical combat casualty care tenets to provide safe care.
   (e) Are expected to place oral endotracheal tubes while under fire.
   Answer: D (see page 230)

2. When evaluating victims who were potentially involved in a closed space explosion, which of the following is most consistent with such an injury pattern?
   (a) Compound humerus fracture.
   (b) Severe concussion.
   (c) Bilateral pulmonary contusions.
   (d) Vertical shear pelvis fracture.
   (e) Gastric rupture.
   Answer: C (see page 228)

3. In the event of a nuclear, biologic, and chemical (NBC) terror event, the most appropriate kind of suit for a chemical release is a:
   (a) Mission-Oriented Protective Posture (MOPP) suit.
   (b) Level 4 suit.
   (c) ½ inch neoprene.
   (d) SCBA gear.
   (e) Nomex suit.
   Answer: A (see page 228)

4. Which of the following is the most rapidly growing terror threat across North America?
   (a) Nuclear terrorism.
   (b) Biologic terrorism.
   (c) Cyberterrorism.
   (d) Sleeper cell emplacement.
   (e) IED distribution.
   Answer: C (see page 229)

5. Bystander response to emergency events is associated with:
   (a) Improved outcomes from emergency care.
   (b) Reduced time to hemorrhage control.
   (c) Enhanced transport to regional facilities.
   (d) All of the above.
   (e) None of the above.
   Answer: D (see page 230)

Chapter 29: Tactical Emergency Medicine, Procedures, and Point-of-Care Evaluation in Austere Environments

1. Which of the following are true regarding a physician practicing in an austere environment?
   (a) Most scoop and run and therefore do not care for patients for prolonged periods of time.
   (b) Tactical physicians carry long guns in addition to medical supplies.
   (c) Along with SWAT team members, they are the first to enter buildings.
   (d) Tactical physicians carry more equipment than SWAT team members.
   (e) All of the above.
   Answer: D (see page 233)

2. What might a medical bag typically contain?
   (a) Lava rock product.
   (b) Solar recharging kits.
   (c) Antiparasitics.
   (d) Ultrasound.
   (e) All of the above.
   Answer: E (see page 234)

3. Use of the eFAST by the tactical physician include ruling out all except:
   (a) Cardiac injury.
   (b) Pneumothorax.
   (c) Ischemic bowel.
   (d) Cholecystitis.
   (e) Head injury.
   Answer: C (see page 235)

4. The tactical physician may not perform which of the following interventions:
   (a) Intraosseous access.
   (b) Tube thoracostomy.
   (c) Endotracheal tube placement.
   (d) Amputations.
   (e) Central line vascular access.
   Answer: D (see page 235)

5. Which one of the following facts regarding tactical and austere medicine is true?
   (a) Improvisation is critical.
   (b) Imaging technology must be portable.
   (c) Provide same procedures as in a trauma bay.
   (d) Limited backup, evacuation options, and resources.
   (e) All of the above.
   Answer: E (see page 236)

Chapter 30: Trauma in Austere Environments: Cold Injury and Hypothermia

1. Cold injury can be classified as the following:
   (a) Systemic injury, cold injury, and non-freezing cold injury.
   (b) Systemic injury and hypothermia.
   (c) Hypothermia and frostbite.
   (d) Systemic injury, freezing cold injury, and frostbite.
   (e) Systemic injury, freezing cold injury, and non-freezing cold injury.
   Answer: E (see page 237)

2. Severe hypothermia can present with the following symptoms:
   (a) Shivering, confusion, and drowsiness.
   (b) Cardiac arrhythmias.
   (c) Temperatures between 30 and 35 °C.
   (d) A and B.
   (e) A, B, and C.
   Answer: D (see page 237)

3. Which four factors are implicated in causing hypothermia?
   (a) Convection, conduction, radiation, and evaporation.
   (b) Impedance of circulation, coagulation, conduction, and convection.
   (c) Impedance of circulation, increased loss of heat, decreased thermogenesis, and impairment of thermoregulation.
   (d) All of the above.
   (e) None of the above.
   Answer: C (see page 238)

4. The following facts apply to non-freezing cold injury:
   (a) Is an injury that occurs from prolonged exposure to wet conditions and temperatures just above freezing.
   (b) Affects the hands and feet.
   (c) Due to microvascular endothelial damage, stasis, and vascular occlusion.
   (d) Burning sensation, blisters, and ulceration can occur.
   (e) All of the above.
   Answer: E (see page 239)

5. Management of cold injuries does not include which of the following principles:
   (a) Other life-threatening injuries may take precedence over the cold injury.
   (b) Prevention of heat loss.
   (c) Rapid restoration of normothermia.
   (d) Prevention of cardiac arrhythmias.
   (e) Active core rewarming should be considered in severe cases.
   Answer: C (see page 239)

Chapter 31: War Zones and Biological Warfare

1. What are the potential difficulties associated with trauma care in the warzone?
   (a) Constantly changing team members.
   (b) Multicasualty and mass casualty events.
   (c) Potential team member exposure to harm.
   (d) All of the above.
   (e) None of the above.
   Answer: D (see page 243)

2. A helpful strategy for optimizing trauma team dynamics in the warzone is?
   (a) Frequent addition of new team members.
   (b) Integrating unfamiliar techniques and procedures during mass casualty incidents.
   (c) Ongoing exercises and simulation.
   (d) Minimizing communication between medical specialists involved in patient care.
   (e) Speaking as loudly as possible so that everyone can hear.
   Answer: C (see page 244)

3. How is war zone trauma team care and care during biologic warfare similar?
   (a) Potential for harm to team members.
   (b) Preparation and simulation are key considerations to optimize team performance.
   (c) Can be psychologically difficult for team members.
   (d) All of the above.
   (e) None of the above.
   Answer: D (see pages 245, 246)

4. Which of the following is considered a bacterial agent of biological warfare?
   (a) Hemorrhagic fevers.
   (b) Plague.
   (c) Ricin.
   (d) Smallpox.
   (e) Influenza.
   Answer: B (see page 244)

5. Decontamination using soap and water for agents of biologic warfare should be considered for?
   (a) Always for all patients.
   (b) Only for patients with unknown contaminants.
   (c) Never as it is not indicated.
   (d) Not sufficient, as dilute bleach and water solutions are the standard for decontamination.
   (e) Water only, not soap.
   Answer: A (see page 246)

Chapter 32: Nuclear Injuries

1. Which of the following facts regarding weaponry physics is NOT true?
   (a) Fission employs high-density elements, with a heavy unstable nucleus, that splits into two or more lighter nuclei releasing a vast quantity of energy.
   (b) Fusion combines light nuclei to form a heavier nucleus-bearing product and produces vast amounts of thermal energy and radiation.
   (c) Radiological dispersion devices (RDD) are munitions that cause a purposeful dissemination of radioactive material without nuclear detonation.
   (d) Dirty bombs undergo fission readily and were the first uranium-based weapons used in the First World War.
   (e) All of the above are true.
   Answer: D (see pages 249, 250)

2. The three main methods of injury that occur from thermonuclear injuries are?
   (a) Initial blast injuries resulting in severe internal tissue disruption.
   (b) Thermal effects which can cause severe burns.
   (c) Radiation which can affect cellular function in various ways.
   (d) All of the above.
   (e) None of the above.
   Answer: D (see page 250)

3. With regard to radiation, which of the following applies?
   (a) Alpha particles have a limited airborne range and cause the least structural cellular damage.
   (b) Beta particles have a range of a few meters and are more destructive than alpha particles.
   (c) Gamma radiation can only be stopped by concrete or lead.
   (d) Beta particles penetrate the human body deeply and can lead to subsequent internal irradiation.
   (e) The scale used for quantitative measure of radiation is known as the Geiger scale.
   Answer: C (see page 250)

4. Initial medical management of a patient with a nuclear injury includes?
   (a) Administration of potassium iodide.
   (b) Obtaining fecal and urine samples to measure the amounts of radiation present.
   (c) Blood tests including serial platelet counts to assess severity of radiation exposure.
   (d) Decontamination of the patient with copious amounts of diluted bleach.
   (e) Obtaining IV access and replenishing any lost circulatory volume.

   Answer: A (see page 251)

5. Which of the following facts regarding radiation hazards is NOT true?
   (a) External radiation hazard is when the radiation is external to the body.
   (b) Internal radiation hazard is when radioactive material enters the body.
   (c) With external radiation hazard, if one moves away from the source, the amount of radiation the body receives decreases.
   (d) The three main routes of entry regarding internal radiation includes: inhalation, ingestion, and injection.
   (e) If a substance undergoes alpha decay, then areas in close contact are not exposed to high-energy radiation.

   Answer: E (see page 251)

Chapter 33: Trauma and Surgical Capabilities in Space Exploration

1. Exploration missions have an increase risk of injuries, including which of the following?
   (a) Falls can occur as a result of exposure to gravitational forces.
   (b) Orthopedic injuries due to bone and muscle degradation from microgravity.
   (c) Deconditioning of the cardiovascular system jeopardizes physiological responses to traumatic insults.
   (d) Wound healing is delayed in microgravity conditions.
   (e) All of the above.

   Answer: E (see page 253)

2. Physiological changes in spaceflight include all of the following EXCEPT?
   (a) There is a shift in body fluid from the head and torso to the lower extremities.
   (b) There is a decrease in erythropoietin secretion.
   (c) Cardiovascular reserve is reduced, and the sympathetic responses are altered with greater beta receptor sensitivity.
   (d) Loss of bone density with weightlessness.
   (e) Suppression of cellular immunity with microgravity.

   Answer: A (see page 254)

3. Which of the following are potential issues when performing surgery in microgravity conditions?
   (a) Prevention of clotting.
   (b) Maintenance of a sterile field.
   (c) Use of ACLS drugs.
   (d) All of the above.
   (e) None of the above.

   Answer: B (see page 255)

4. Challenges regarding surgical care in microgravity conditions include?
   (a) Atmospheric contamination with CO_2.
   (b) Decreased venous bleeding.
   (c) Arterial bleeding is difficult to entrap.
   (d) Not enough areas for waste disposal.
   (e) Rapid wound healing.

   Answer: C (see page 257)

5. Damage control procedures in space include which of the following?
   (a) Placing packs around hollow organs.
   (b) Closing the abdominal wall to prevent bleeding.
   (c) Use of fibrin glue and sealants during laparotomy.
   (d) Plaster casting of orthopedic injuries.
   (e) Flexible aluminum splints around complex fractures.

   Answer: C (see page 260)

Chapter 34: Designing a Simulation Curriculum

1. Simulated clinical immersion (SCI) with guided experiences in simulated environments is a valuable instructional method for which of the following skills?
   (a) Situational awareness.
   (b) Decision making.
   (c) Communication.
   (d) Teamwork.
   (e) All of the above.

   Answer: E (see page 267)

2. Which of the following is NOT a step in Sherbino and Frank's systematic educational design framework for designing an educational curriculum?
   (a) Conducting a needs assessment.
   (b) Developing learning objectives.
   (c) Selecting and implementing instructional methods.
   (d) Tailoring instructional methods to individual learning styles.

(e) Assessing learning.
Answer: D (see page 267)

3. Which of the following is usually the first step in designing an educational curriculum?
   (a) Developing learning objectives.
   (b) Assessing learning and competence.
   (c) Conducting a needs assessment.
   (d) Selecting and implementing appropriate instructional methods.
   (e) None of the above.
   Answer: C (see page 267)

4. Sources of information for a needs assessment can include?
   (a) Accreditation survey results.
   (b) Examination results from previous student cohorts.
   (c) Questionnaire results from learners.
   (d) All of the above.
   (e) None of the above.
   Answer: D (see page 268)

5. Which of the following are NOT elements of well-written learning objectives?
   (a) A defined learner.
   (b) A time reference.
   (c) A performance descriptor using non-observable verbs.
   (d) The conditions under which learner will learn.
   (e) All of the above.
   Answer: C (see page 270)

Chapter 35: Designing Multidisciplinary Simulations

1. Which of the following pairs regarding technology and fidelity in simulation is correct?
   (a) Phone simulation is low technology and low fidelity.
   (b) Mannequin simulation is high technology and low fidelity.
   (c) Standardized patient is high technology and high fidelity.
   (d) Role play is low technology and low fidelity.
   (e) Computer-based simulation is high technology and high fidelity.
   Answer: D (see page 274)

2. Which one of the following statements applies to simulation fidelity?
   (a) Physical fidelity is the degree to which simulation recreates the look, feel, sound, and smell of the real world.
   (b) Functional fidelity refers to how realistically the simulator reacts to input from the operator.
   (c) Psychological fidelity represents the participant's emotional response or "buy-in."
   (d) All of the above.
   (e) None of the above.
   Answer: D (see page 273)

3. Which of the following should not be considered when designing a basic scenario?
   (a) Identify major problem areas.
   (b) Get input from all relevant experts.
   (c) Draft a scenario and curriculum.
   (d) Refine the curriculum using a modified Delphi approach.
   (e) Beta-test using a small number of learners.
   Answer: E (see page 278)

4. Steps of scenario design include which of the following?
   (a) Identify the educational needs of the curriculum.
   (b) Include at least one new skill from Johnson's educational domains.
   (c) Tailor the simulation more attitudinal for junior learners and more cognitive for senior ones.
   (d) Allow repetition of the same scenario until mastery.
   (e) Collect data for publication purposes.
   Answer: D (see page 277)

5. In thinking about maximizing simulation scenarios, which of the following is NOT correct?
   (a) Telephone simulation provides many of the putative benefits of high-fidelity simulation but with little cost.
   (b) Simulations can include forced hand-offs since handing a patient from one team to another can be perilous.
   (c) Doing rather than thinking is known as system two behavior and can be used for simulations.
   (d) Physician leaders may not communicate what they are doing or why; to mitigate this, simulations can be redone but with the physician-leader blindfolded.
   (e) All of the above.
   Answer: C (see page 279)

Chapter 36: Constructive Debriefing for Trauma Team Education

1. Which of the following facts are true regarding debriefing structure?
   (a) The description phase allows one to identify the initial thoughts and reactions of the participant.
   (b) The reaction phase allows one to define the learning objectives most important to participants.
   (c) The analysis phase allows one to state take-home messages and how the lessons learned apply to clinical practice.

(d) The summary phase allows one to integrate selected topics raised by participants.
(e) All of the above.
Answer: C (see page 284)

2. Which of the following are methods of debriefing?
(a) Advocacy Inquiry.
(b) Directive Feedback.
(c) Plus Delta.
(d) Blended.
(e) All of the above.
Answer: E (see page 284)

3. Which of the following regarding advocacy inquiry (AI) debriefing methods is NOT true?
(a) AI attempts to uncover the "frame" or rationale behind a participant's behavior.
(b) AI is particularly useful when the rationale behind an action is not clear or immediately apparent.
(c) AI uses a series of hypothetical statements to uncover performance issues.
(d) By using AI, the facilitator can engage learners in discussion and have teams address performance issues and answer questions on their own.
(e) AI often takes much time to practice and master this technique.
Answer: C (see page 285)

4. Which of the following regarding debriefings is NOT true?
(a) It has not yet become a standard of practice in medicine.
(b) Debriefing is a stress reduction intervention.
(c) It is difficult to determine debriefing effectiveness.
(d) Quantitative debriefings include the addition of actual quantitative patient information gathered from bedside devices, patient monitors, and records.
(e) The use of playback of actual resuscitation events is an effective way of improving rescuer knowledge and team performance.
Answer: B (see page 286)

5. Using the advocacy inquiry debriefing technique, which of the following steps match the possible statements or phrases?
(a) Observation: " I saw that…."
(b) Facilitator point of view: " I noticed that…."
(c) Learner point of view: " I was wondering…."
(d) Facilitator point of view: " How did you see it…."
(e) Learner point of view: " At the time I was thinking…."
Answer: A (see page 285)

Chapter 37: Program Evaluation and Assessment of Learning

1. According to Miller's evaluation framework, the "shows how" level refers to?
(a) Evaluating whether a learner's clinical skills are improved in the clinical setting.
(b) Whether a learner can demonstrate a change in clinical skills and performance.
(c) Whether a learner's knowledge has improved.
(d) The instructor's satisfaction level with the learner's clinical skills.
(e) The learner's satisfaction with the simulation event.
Answer: B (see page 290)

2. Process-based program evaluation looks at?
(a) Determining whether the desired outcomes of a program have occurred.
(b) The tangible results of a program in terms of costs, quality, and efficiency.
(c) Determining how a program was implemented, as well as why it did or did not work as intended.
(d) Resources available and utilized during the program.
(e) All of the above.
Answer: C (see page 291)

3. Reliability in assessment refers to?
(a) The ability to consistently differentiate between candidates.
(b) The systematic investigation of a program's worth.
(c) The degree of confidence one has in the inferences drawn based on the scores generated by one's assessment.
(d) The extrapolations one makes from the assessment context to the clinical context.
(e) None of the above.
Answer: A (see page 291)

4. Threats to validity include?
(a) Poor reliability.
(b) Lack of authenticity.
(c) Construct underrepresentation.
(d) All of the above.
(e) None of the above.
Answer: D (see page 292)

5. To increase authenticity of an assessment educators should do which of the following?
(a) Match or align the assessment setting with the clinical setting.
(b) Increase the face validity of an assessment.

(c) Increase the number of cases or stations in one's assessment.
(d) Increase the number of discrimination points on one's scale.
(e) Increase the number of assessments performed.
Answer: A (see page 292)

Chapter 38: Teaching Technical and Procedural Skills

1. In the psychomotor domain of learning, skills autonomy refers to:
   (a) Automatic performance of skills in live patients.
   (b) Performance of the skills once without supervision.
   (c) Performance of skills repeatedly in a live patient.
   (d) Performance of skills repeatedly in a laboratory setting.
   (e) None of the above.
   Answer: D (see page 295)

2. The principles of psychomotor skills development include:
   (a) Research, conceptualization, verbalization, practice, feedback, revision, and skills mastery.
   (b) Research, visualization, verbalization, skills mastery, and skills autonomy.
   (c) Conceptualization, visualization, verbalization, practice, feedback, skills mastery, and skills autonomy.
   (d) Conceptualization, design, verbalization, practice, feedback, and skills mastery.
   (e) Conceptualization, design, practice, feedback, skills mastery, and skills autonomy.
   Answer: C (see pages 296, 297)

3. Of the following, which is the highest level in Bloom's taxonomy of the cognitive domain?
   (a) Knowledge.
   (b) Evaluation.
   (c) Comprehension.
   (d) Characterization.
   (e) All of the above.
   Answer: B (see page 296)

4. How would you best remediate a student who performs a skill incorrectly after instruction?
   (a) Provide further instruction.
   (b) Advise repeated practice of the skill.
   (c) Observe another student doing the skill.
   (d) Identify and correct psychomotor steps.
   (e) None of the above.
   Answer: D (see page 297)

5. What is the first step in the taxonomy of the Affective Domain of learning?
   (a) Receiving.
   (b) Valuing.
   (c) Responding.
   (d) Characterization.
   (e) All of the above.
   Answer: A (see page 296)

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