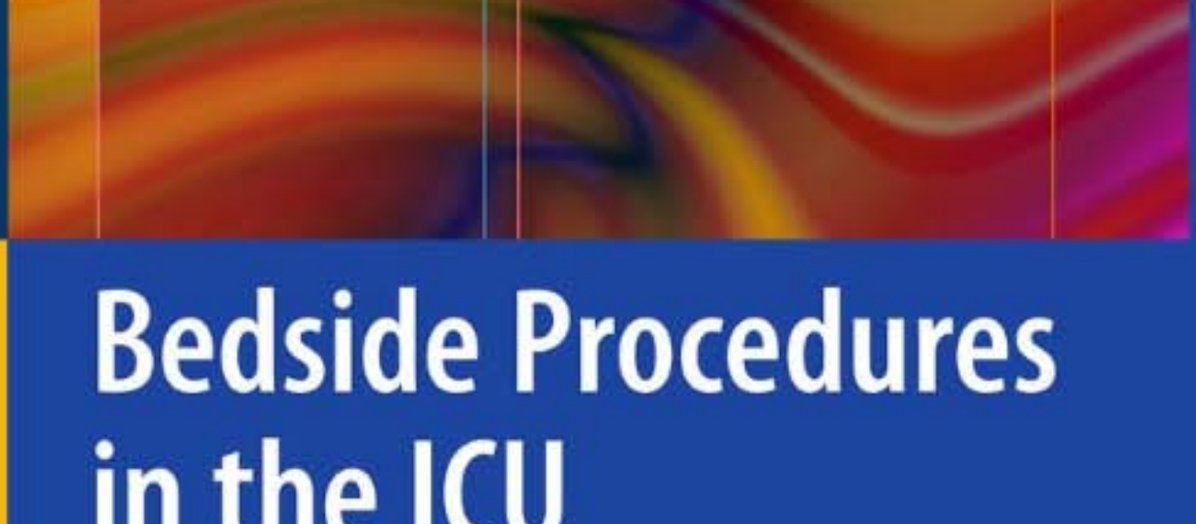
Florian Falter
Editor



Bedside Procedures in the ICU

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Preface

This book provides an easy to follow guide to the most commonly performed procedures in the Intensive Care Unit. It is has been written with the newcomer looking for step by step guidance as well as the seasoned practitioner looking to jog their memory in mind.

"Bedside Procedures" is not intended to replace more voluminous intensive care textbooks. I hope that by discussing 20 procedures all the way from indication to the management of possible complications this book will be useful in clinical practice, preparing for examinations and as a teaching tool.

I would like to thank all those who helped preparing the manuscript. My special thanks goes to the authors who contributed their expertise by writing the chapters for this book.

Cambridge, December 2011 Florian Falter

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Chapter 1
Sedation and Analgesia

Christiana C. Burt and Jurgens Nortje

Targeted sedation with appropriate analgesia is vital not only to facilitate humane therapeutic intervention, but also to minimize the duration of ventilation and to allow as much patient co-operation as possible.

Duration of action of drugs, their effects on organs and physiology, as well as their kinetics in organ failure are all important considerations. Sedation scoring is becoming routine to avoid over-sedation in particular, and pain scoring allows directed analgesia. The likelihood of pain, even in sedated patients, should be considered before any intervention. Clear communication and reassurance should always be the foundation of peri-procedural management, with sedatives and analgesics administered as required.

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Indications

- Sedation:
  - Relieve anxiety
  - Tolerate invasive procedures
  - Facilitate controlled mechanical ventilation
  - Facilitate interventions and routine nursing care
  - Tolerate excessive noise, ambient light and stimulation
  - Reduce intracranial hypertension
  - Reduce O_2 consumption
  - Treat hyperactive delirium
  - Treat convulsions or status epilepticus
- Analgesia:
  - Expected post-operative pain after surgical procedures
  - Invasive procedures
  - Drains, tubes, lines in situ
  - Infection
  - Ulcers, sores
  - Routine nursing care (e.g. dressing changes)
  - Physiotherapy and mobilization
  - Prolonged immobility
  - Pre-existing diseases or chronic pain conditions commonly, back and joint pains compounded by immobility
  - Trauma

Pharmacological Agents

Through appropriate application of scoring systems, the requirement for sedative, analgesic, antipsychotic or combinations of these agents (see Tables 1.1 and 1.2) can be determined.

The intravenous administration route is preferred for most sedative and analgesic drugs in the ICU. Intramuscular and topical routes may be unreliable with altered perfusion and variable absorption in hemodynamically unstable patients.

TABLE 1.1 Sedative and anesthetic drugs commonly used

Drug	Uses	IV dose	Best indication	Problems
Benzodiazepines				
Midazolam	(i) Anterograde amnesia (ii) Anxiolysis (iii) Sedation (iv) Induction of anesthesia (v) Anti-convulsant	Bolus: 1–5 mg Infusion: 0.02–0.2 mg/kg/h	(i) Short sedation in hemodynamic instability (bolus dose) (ii) Infusion if prolonged duration of ventilation is expected (>72 h)	(i) duration of action with prolonged infusion (ii) duration of action with Ca^{2+} channel blockers, amiodarone, macrolide antibiotics, azole antifungals
Lorazepam	As for midazolam	Bolus: 2–4 mg Infusion: 2–4 mg/h	Seizure control	Independent risk factor for delirium

(continued)

Table 1.1 (continued)

Drug	Uses	IV dose	Best indication	Problems
Anesthetic agents				
Propofol	(i) Amnesia	Bolus: 0.3–3 mg/kg	Short term sedation	(i) Hypotension due to vasodilatation and myocardial depression
	(ii) Anxiolysis			(ii) Respiratory depression
	(iii) Sedation			(iii) Propofol infusion syndrome (>5 mg/kg/h for >72 h)
	(iv) Induction of anesthesia	Infusion: 0.3–5 mg/kg/h		(iv) Hypertriglyceridemia
	(v) Anti-convulsant			

Drug	Uses	IV dose	Best indication	Problems
Thiopentone	(i) Induction of anesthesia (ii) Anti-convulsant	Bolus: 2–7 mg/kg for rapid sequence induction	(i) Status epilepticus	(i) Accumulation if repeated doses or as infusion
	(iii) Sedation	Infusion: 2–7 mg/kg/h	(ii) Infusion for refractory intracranial hypertension to achieve 'burst suppression'	(ii) Hypotension due to vasodilatation and myocardial depression (beware in hypovolemia)
Ketamine	(i) Analgesia (ii) Dissociative anesthesia	Bolus (sedation): 0.3–0.5 mg/kg	Anesthesia and analgesia in cardiovascular compromise	(i) Raised intracranial pressure
	(iii) Bronchodilation	Bolus (anesthesia): 0.5–2 mg/kg		(ii) Tachycardia, hypertension
	(iv) Chronic pain	Infusion: 0.2 mg/kg/h		(iii) Hallucinations

(continued)

Table 1.1 (continued)

Drug	Uses	IV dose	Best indication	Problems
α_2-agonists				
Clonidine	(i) Sedation (ii) Chronic pain (iii) Anxiolysis	Bolus: 0.15–0.3 mg 8 hourly Infusion: up to 0.3 mg/h	(i) Agitation, particularly when accompanied by hypertension (ii) Opioid withdrawal	(i) Drowsiness (ii) Initial hypotension (iii) Rebound hypertension on discontinuation
Dexmedetomidine	(i) Anxiolysis (ii) Sedation (iii) Analgesia	Loading dose: 1 mcg/kg over 10–20 min Infusion: 0.2–1.4 mcg/kg/h	(i) Short term sedation (<24 h) (ii) Hyperactive delirium in cardiovascularly stable patients	(i) Bradycardia (ii) Hypotension
Neuroleptics				
Haloperidol	Sedation	Bolus: 2.5–5 mg per dose, max. 40 mg/day	Acute agitated delirium	(i) Extrapyramidal effects (ii) Prolongation of QT interval with risk of Torsade de pointes

TABLE 1.2 Analgesic drugs commonly used

Drug	Uses	IV dose	Best indication	Problems
Opioids				
Morphine	(i) Analgesia (ii) Suppression of cough reflex	Bolus: 2.5–5 mg, repeated as needed (20 min to achieve maximum effect) Infusion: 1–10 mg/h	Analgesia for moderate to severe pain	(i) Respiratory depression (ii) Hallucinations (iii) Nausea and vomiting (iv) Reduced GI motility (v) Urinary retention (vi) Tolerance and dependence (vii) Rash, itching (viii) Bronchospasm (ix) Accumulation of active metabolites in renal failure

(continued)

Table 1.2 (continued)

Drug	Uses	IV dose	Best indication	Problems
Fentanyl	As for morphine	Bolus: 0.5–2 mcg/kg Infusion:1–5 mcg/kg/h	(i) Bolus for rapid onset analgesia (ii) Infusion for sedation/analgesia	(i) As for morphine, but no active metabolites and less histamine release (ii) Large doses may cause chest wall rigidity and difficulty ventilating.
Sufentanil	As for morphine	2–8 mcg/kg bolus up to 1 mcg/kg/h infusion	As for Fentanyl	As for Fentanyl
Remifentanil	As for morphine	Bolus: 0.5–1 mcg/kg Infusion: 0.0125–1 mcg/kg/min	Analgesia for short procedures	(i) Ultra short duration of action, not useful for analgesia post procedure (ii) Bradycardia, hypotension, particularly when given as bolus (iii) Chest wall rigidity with difficulty ventilating

Drug	Uses	IV dose	Best indication	Problems
Pethidine (Meperidine)	Analgesia	Bolus: 5–10 mg Infusion: 10–50 mg/h	As for morphine, but sometimes better tolerated	(i) As for morphine (ii) Contraindicated with MAO inhibitor use
Tramadol	Analgesia Less respiratory depression than other opioids	Bolus: 1–2 mg/kg, slowly every 4–6 h, max. 600 mg/day	Analgesia in patients intolerant of morphine and 'pure' opioids	(i) Contraindicated in epilepsy or patients taking MAO inhibitors (ii) Nausea, dizziness, dry mouth

- Morphine, fentanyl, sufentanil or pethidine can be administered via patient-controlled (PCA) or nurse-controlled (NCA) delivery systems in appropriate patients, also allowing background infusions or addition of sedative drugs as required.
- The use of non-steroidal anti-inflammatory drugs (NSAIDs) needs to be carefully weighed against the significant adverse effects of gastro-intestinal bleeding, platelet inhibition and renal injury (particularly in hypovolemia, the elderly and pre-existing renal impairment).
- Acetaminophen (paracetamol) is used for mild pain or discomfort, and as an antipyretic agent, however hepatotoxicity is a risk in the critically ill.
- Although some interventions may be suitable for the use of local or regional anesthetic techniques, issues such as risk-benefit, consent, duration and degree of difficulty with distorted anatomy may preclude their use.

Monitoring Sedation, Agitation and Analgesia

Scoring systems are available to assess sedation, agitation and analgesia on the ICU and allow targeted individualized therapy. These systems need to be simple, accurate and reproducible. Frequent scoring is required as levels of pain, sedation and agitation can vary constantly in critical illness. Use of scoring also enhances handover and communication between healthcare providers.

- Sedation and agitation scoring
  - The Ramsay Sedation Scale (RSS):
    First described in 1974, the 6 level RSS continues to be widely used for monitoring sedation in ICU (see Table 1.3). For a bedside intervention, the desired sedation level will vary according to the procedure planned. For procedures requiring muscle relaxation with neuromuscular blockers (NMBs) e.g. percutaneous tracheostomy, a deeper level of sedation (Ramsay 4–5) should be ensured before the NMB is administered. The use of NMB precludes the subsequent use of sedation scales.

Table 1.3 Ramsay sedation scale

1	Patient awake: anxious, agitated or restless
2	Patient awake: cooperative, orientated and tranquil
3	Patient awake: responds to commands only
4	Patient asleep: brisk response to glabellar tap or loud auditory stimulus
5	Patient asleep: sluggish response to glabellar tap or loud auditory stimulus
6	Patient asleep: no response to glabellar tap or loud auditory stimulus

  - The Richmond Agitation-Sedation Scale (RASS): Also widely in use, the RASS is a 10-point scale with four levels for anxiety or agitation, one level for calm and alert, and five levels of sedation. Developed to allow more precise titration of sedatives, RASS is more sensitive at scoring agitation (see Table 1.4).
  - Other sedation scoring systems in use include: the Sedation Agitation Scale (SAS), the Motor Activity Assessment Scale, the Vancouver Interactive and Calmness Scale, the Adaptation to Intensive Care Environment (ATICE) instrument and the Minnesota Sedation Assessment Tool (MSAT).

- Pain scoring
  - The most reliable pain assessment is self-reporting by patients in whom communication is possible, where pain location, nature and aggravating or alleviating factors can be expressed. Pain intensity can be assessed using verbal rating scales (VRS), visual analogue scales (VAS), or numeric rating scales (NRS). Most scales score from 0 to 10 points, with 10 being the most severe pain.
  - In patients where communication is not possible, subjective observation of pain-related behavior such as movement (localizing), facial expression (grimacing) and posturing or fist clenching is important. Physiological indicators of pain such as respiratory rate, heart rate,

Table 1.4 Richmond agitation-sedation scale

+4	Combative	Overtly combative or violent, immediate danger to staff
+3	Very agitated	Pulls on or removes tube(s) or catheter(s) or exhibits aggressive behavior toward staff
+2	Agitated	Frequent non-purposeful movement or patient-ventilator dys-synchrony
+1	Restless	Anxious or apprehensive but movements not aggressive or vigorous
0	Alert and calm	
−1	Drowsy	Not fully alert, but has sustained (>10 s) awakening, with eye contact, to voice
−2	Light sedation	Briefly (<10 s) awakens with eye contact to voice
−3	Moderate sedation	Any movement (but no eye contact) to voice
−4	Deep sedation	No response to voice, but any movement to physical stimulation
−5	Unrousable	No response to voice or physical stimulation

blood pressure and sweating should be assessed, and re-assessed following analgesic therapy.

- Other tools have been used in non-communicative patients to assess pain. These include the COMFORT scale and FLACC observational tool (both adapted from pediatric ICU) and the Behavior Pain Score (BPS) which is based on facial expression, upper limbs movement and compliance with mechanical ventilation.
- If there are signs of pain, analgesics should be administered first in preference to sedatives.

A Suggested Approach to Sedation and Analgesia for Bedside Procedures

Individual units have their own protocols and preferences for choice and mode of delivery of sedative and analgesic agents. If a patient is settled on a regimen of sedation and analgesia it is prudent to maintain it with additions as required to cover the bedside procedure. The aim is to cause minimal disruption with safe, effective and comfortable conditions for the patient and the operator.

- Preparation for all bedside ICU procedures:
  - Be aware of diagnosis, pertinent history and coagulation status
  - Assess sedation and/or pain score and anticipate the impact of the procedure to determine likely additional doses of sedatives and analgesics
  - Explain the reason for an intervention to the patient and obtain consent if possible
  - Ensure patent intravenous (IV) access suitable for rapid volume infusion if needed
  - IV fluid/vasoconstrictors/inotropes should be available as required
  - Check current inotrope or vasoconstrictor infusion rates and reserves
  - Check current level and mode of respiratory support
  - Check current sedative or analgesia infusion rates and reserves
  - Consider having additional sedative, analgesic and neuromuscular blocking agents available for bolus use
  - Consider possibility of local anesthetic infiltration (with attention to maximum dose)
  - Consider a separate operator to manage sedation and analgesia for more complex procedures
  - For intubated spontaneously breathing patients: Ensure ventilator settings are set to allow ‘back-up’ ventilation if respiratory rate decreases or apnea occurs

  - For non-intubated patients: Ensure appropriate airway equipment and personnel are available if respiratory rate decreases or apnea occurs

Complications

- Inadequate sedation/analgesia:
  - Anxiety
  - Discomfort, pain
  - Inadequate sleep, disorientation, exhaustion, agitation
  - Non-intentional removal of lines, endotracheal tube, catheters, drains
  - Injury to patient or healthcare providers
  - Patient-ventilator dys-synchrony
  - Tachycardia, hypertension, increased myocardial O_2 consumption
  - Increased cerebral O_2 consumption with raised intracranial pressure
- Excessive sedation/analgesia:
  - Respiratory depression
  - Increased duration of intubation and ventilation
  - Increased risk of nosocomial pneumonia
  - Increased length of ICU stay
  - Increased requirement for neurological assessment and imaging
  - Hemodynamic instability through vasodilatation and myocardial depression requiring vasoconstrictors and inotropes
  - Possible increased likelihood of post-traumatic stress disorder (especially with marked amnesia)
  - Increased risk of pressure sores and nerve injury

Thorough pre-procedural assessment of analgesic and sedation requirements may minimize the impact of the above complications, particularly in the sickest patients.

Chapter 2
Airway Management and Intubation

Monica Trivedi

A number of procedures carried out in an ICU require either a level of sedation, which can only be achieved with airway support (e.g. cardioversion) or can only be safely done under general anesthesia with airway protection (e.g. PEG insertion). Airway management is also one of the first steps in stabilizing the critically ill patient, allowing airway protection and optimizing oxygen delivery.

Consent

Consent for airway management is not normally sought separately but tends to be part of the information given to patients when a procedure is explained to them.

Basic Airway Maneuvers

Basic airway maneuvers are only suitable for short-term use, and may need to be followed by establishment of a definitive airway.

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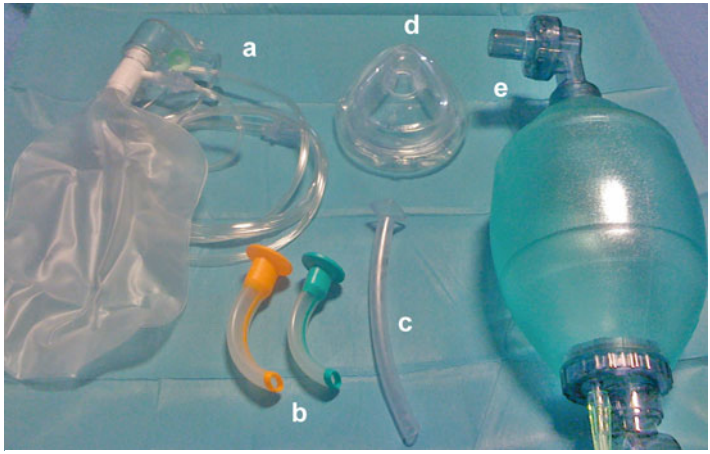

FIGURE 2.1 Basic airway equipment: (**a**) reservoir bag to administer high flow O_2, (**b**) oropharyngeal (Guedel) airways, large and medium, (**c**) nasopharyngeal airway, (**d**) face mask with soft cuff, (**e**) self inflating bag to allow manual positive pressure ventilation (Ambu-Bag)

Indications

- Airway obstruction, which is can be recognized by
  - Tachypnea,
  - Stridor,
  - "See-saw" movement of the chest wall.

It is mostly caused by either sedation or CNS depression.

Preparation

- Basic airway equipment (see Fig. 2.1) should be available at every bed space in an ICU and should be checked regularly.

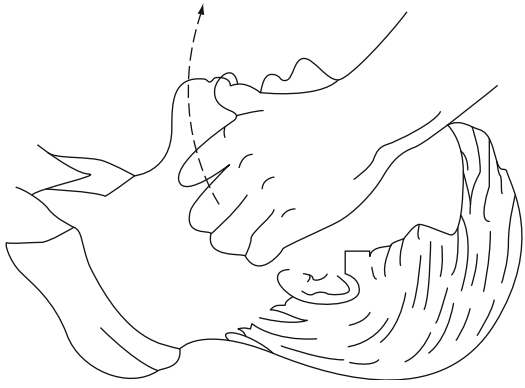

FIGURE 2.2 Jaw thrust

Techniques

- Jaw thrust: Two fingers are placed behind the angle of the jaw on each side, and the is jaw gently lifted straight upwards (see Fig. 2.2).
- Chin lift: The chin is gently lifted and the head tilted back (see Fig. 2.3). Care must be taken in patients with potential cervical spine injury or arthritis.
- Oropharyngeal airway: The airway is inserted into the mouth with the tip facing the palate. After advancing a few centimeters, the airway is rotated through 180° before advancing further (see Fig. 2.4). Generally, only patients with obtunded airway reflexes tolerate oropharyngeal airways. Attempting to insert one in a more awake patient may lead to vomiting and aspiration.
- Nasopharyngeal airway: This airway is better tolerated in the more conscious patient, although insertion can be very uncomfortable. It is gently inserted into a nostril (see Fig. 2.5) – if resistance is felt, the contralateral side should be tried. This procedure is contraindicated in patients with suspected base of skull fracture. Risks and benefits have to

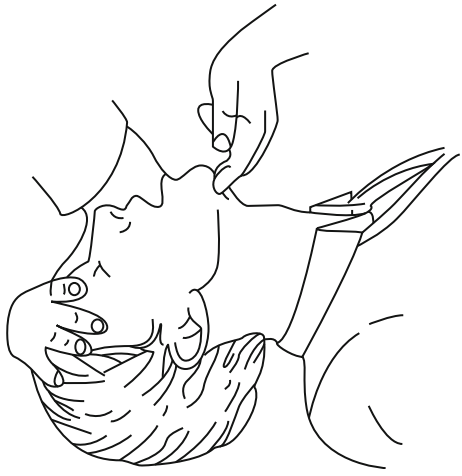

Figure 2.3 Chin lift

Figure 2.4 Insertion of an oropharyngeal airway

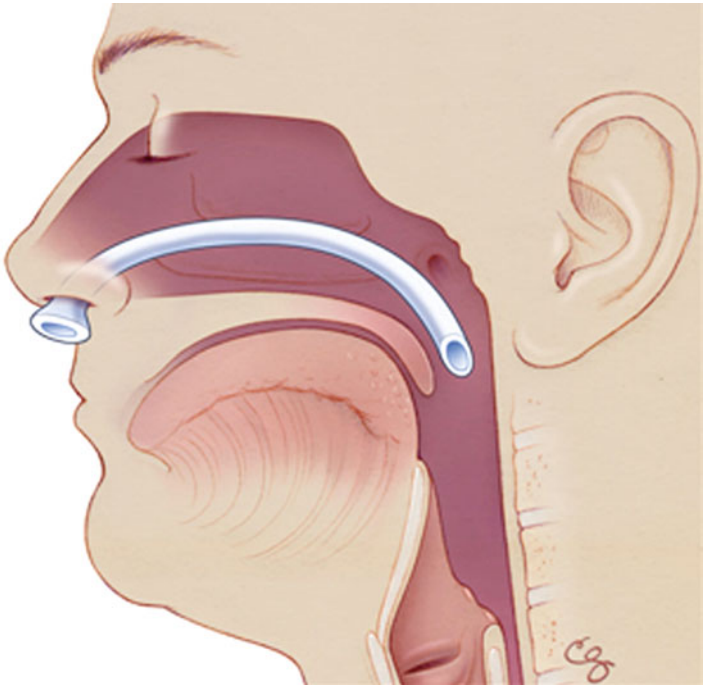

FIGURE 2.5 Insertion of a nasopharyngeal airway

be carefully weighted in anticoagulated patients, as any ensuing epistaxis can be torrential and difficult to treat.

- Suctioning: Secretions, gastric contents or blood can be suctioned from the oropharynx via mouth or nasopharyngeal airway to help protect the airway.

Basic airway support is a temporary measure. The following three scenarios are possible:

- If the patient is making adequate spontaneous respiratory efforts and is protecting their airway, high flow oxygen should be administered via a facemask. Patency of the

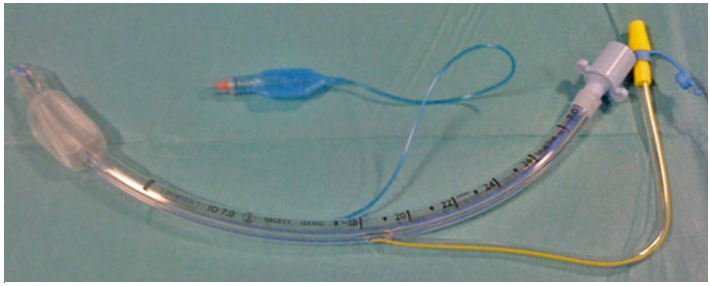

FIGURE 2.6 Endotracheal tube, distal cuff with pilot balloon (*blue*) and subglottic suction port (*yellow*)

airway is confirmed by misting of the mask each time the patient breathes out.

- If the patient is not making an adequate spontaneous respiratory effort, ventilation via a bag valve mask system should be instituted. The decision whether or not to intubate and create a definite airway should not be delayed by much once mask ventilation has been started.
- If the patient is not breathing a definitive airway will be needed, but temporary ventilatory support can be provided with a bag valve mask system attached to high flow oxygen until the patient can be intubated.

Definitive Airway

A cuffed tube in the trachea provides a definitive airway.

- Orotracheal tubes (see Fig. 2.6) are sized according to internal diameter in mm, with sizes 7–9 most commonly used in adult ICU patients. The tip sits at least 2 cm above the carina to ensure ventilation of both lungs. A low-pressure, high-volume cuff at the distal end provides airway protection. It is inflated via a pilot balloon. Some tubes for ICU use have a port for subglottic suctioning above the cuff.

- Nasotracheal tubes are rarely used in adult intensive care patients, as they are associated with higher rates of sinusitis and ventilator-associated pneumonia.
- Tracheostomy tubes (see Chap. 4)

Indications

- Maintaining airway patency in patients with a reduced level of consciousness or requiring sedation.
- Airway protection in patients at risk of aspiration.
- Prevention of complete airway obstruction.
- Ventilation in patients with Type 1 or Type 2 respiratory failure.
- Clearance of bronchial secretions in patients with poor cough.

Preparation

- Depending on the size and the layout of an ICU at least one airway trolley with intubation equipment (see Fig. 2.7) should be in an easily accessible location. It has to be maintained and checked regularly.
- The patient needs to be assessed for potential difficulties of intubation. Factors associated with difficult intubation include
  - Obesity
  - Short wide neck
  - Reduced neck extension
  - Prominent upper incisors
  - Receding chin
  - Reduced mouth opening
  - Presence of beard
  - Swollen tongue
  - Facial trauma

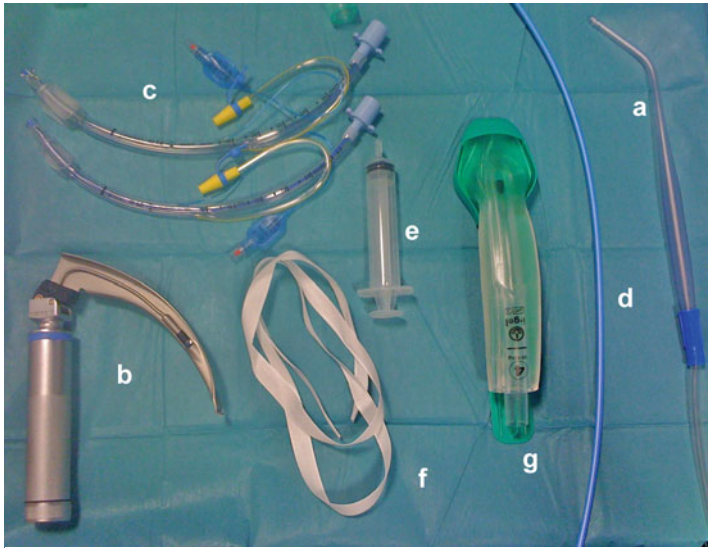

FIGURE 2.7 Equipment needed for intubation: (**a**) suction, (**b**) Macintosh laryngoscope, (**c**) endotracheal tubes of varying sizes, (**d**) bougie in case of difficult intubation, (**e**) syringe to inflate cuff, (**f**) tape to secure tube, (**g**) alternative method of securing airway if intubation fails, e.g. laryngeal mask airway

Depending on the expertise of the operator, the presence of one or more of these factors should prompt a call for more experienced help.

- A sedative and a muscle relaxant are needed for intubation. Emergency drugs in case of hypotension or bradycardia should also be to hand.
- A minimum of ECG, oxygen saturation and noninvasive blood pressure monitoring (NIBP) should be in place.
- At least one trained assistant is required.

Technique

- The patient should be pre-oxygenated with high flow oxygen via a tightly fitting mask for at least 3 min prior to giving

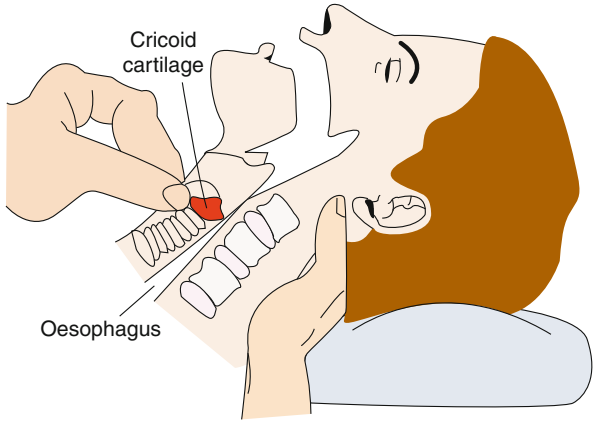

FIGURE 2.8 Cricoid pressure during rapid sequence intubation

intubation drugs. This prolongs the length of time before the patient starts to desaturate during attempts at intubation.

- A sedative drug is usually required, with doses reduced in patients with reduced GCS or cardiovascular instability. Opiates given concurrently may improve cardiovascular stability.
- In patients at risk of aspiration of gastric contents, a rapid sequence technique is used, with a fast acting muscle relaxant and cricoid pressure. It is given by placing thumb and index finger on either side the cricoid ring and applying 30N of pressure. As the cricoid ring is a complete cartilaginous ring, it compresses the esophagus and prevents reflux of gastric contents (see Fig. 2.8). Cricoid pressure should be started as soon as the patient loses their airway reflexes, and should be maintained until a definitive airway is established.
- Once the patient is paralyzed, a Macintosh laryngoscopy blade is inserted until the tip reaches the base of the tongue and lifted upwards and away from the operator until the vocal cords are exposed (see Fig. 2.9). The endotracheal tube is inserted under direct vision through the cords.
- Looking for bilaterally equal chest movement and auscultating for breath sounds on both sides help making sure the

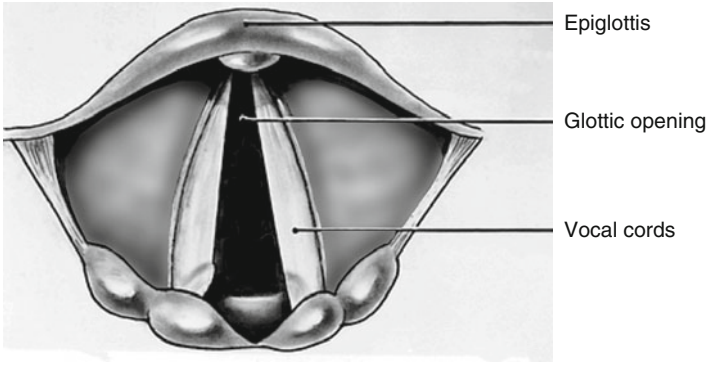

FIGURE 2.9 View on direct laryngoscopy

tube is in the right position. Absent air entry on the left is suggestive of intubation of the right main bronchus. In that case the tube should be withdrawn by 2 cm and auscultation repeated. Position should also be confirmed by monitoring the end-tidal CO_2, and subsequently by chest X-ray to make sure the tube tip at least 2 cm above the carina.

- Once it has been established that the intubation was successful, the tube has to be tied or taped securely into place.
- After successful intubation, the patient should be connected to a ventilator on appropriate settings.
- Sedative infusions are started after intubation for patient comfort and tube tolerance.

Pitfalls

- Maintaining oxygenation is always the highest priority. If the intubation is difficult or oxygen saturations start to fall, it is best to revert to basic airway maneuvers with bag valve mask ventilation.
- If it is difficult to direct the tube into the trachea despite a good laryngoscopic view a bougie can be used as a guide over which to railroad the tube. If there is resistance to passage of the tube through the cords, a smaller size may be needed.

- If the intubation is unsuccessful after two attempts, insertion of a laryngeal mask airway allows oxygenation (but with limited airway protection), while help is summoned.
- In case there is no end-tidal CO_2 trace the circuit should be briefly checked. But if there is doubt about tube position it should be removed immediately and basic airway maneuvers have to be started.

Complications

- A cuff leak may develop at any time the endotracheal tube is in situ. The length of the tube at the incisors should be checked (to ensure the tube has not been dislodged), the cuff re-inflated and pressure checked. Recurrent leaks indicate damage to the cuff and the tube should be changed.
- Accidental extubation can be an emergency situation in the ICU patient. Basic airway maneuvers should be instituted immediately and help summoned to assist with swift re-intubation.
- Ventilator associated pneumonia is a very common ICU-acquired infection, usually due to microaspiration past the endotracheal cuff. Its incidence can be reduced by simple measures such as head-up tilt, oral hygiene and subglottic suctioning of secretions.
- Tracheal stenosis can occur after prolonged periods of intubation. In most cases where prolonged ventilation is anticipated a tracheostomy is performed (see Chap. 4).

Chapter 3
Bronchoscopy

Karthik Santhanakrishnan and Jasvir Singh Parmar

Fibre-optic bronchoscopy (FOB) is an important diagnostic and therapeutic tool in the management of patients with respiratory impairment. Where diagnostic uncertainty exists over patients with respiratory complications a range of investigations can be performed on samples obtained from the lower airways. Therapeutically alleviation of airway obstruction by removal of secretions, tumor or foreign bodies can result in a dramatic improvement in the clinical situation.

Indications

- Diagnostic sampling
- Airway management

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- Relief of airway obstruction
  - Inspissated secretions
  - Tumor debridement
  - Stenting
  - Removal of foreign bodies
- Identification of bleeding points
- Percutaneous tracheostomy (see Chap. 4)
- Instillation of therapeutic agents

Consent

If not intubated and ventilated the indications for the procedure and potential complications associated with performing a FOB should be explained to the patient. Overall FOB is a safe procedure, which is generally well tolerated with very few major complications.

- Patients who are not already ventilated are at risk of deteriorating respiratory function during the procedure. Some patients might even require intubation and mechanical ventilation
- The risk of worsening hypoxemia and subsequent arrhythmia is associated with sedation
- Throat discomfort
- Vocal cord injury
- Epistaxis, if the procedure is performed via the nose in awake patients
- Patients requiring airway intervention have the additional risk of
  - Bleeding (1–5%)
  - Pneumothorax (5–10%)

Preparation

The safe conduct of a bronchoscopy in critically ill patients requires careful preparation and attention to detail.

- The recommended staffing requirements for the procedure are
  - A trained operator
  - One assistant to help with the procedure

  - One assistant to monitor the patient. This member of staff has to be familiar with basic hemodynamic interventions.
- In patients who are not intubated and ventilated it is recommended that an anesthetist is present and emergency airway equipment is immediately available.
- The minimum monitoring requirement throughout the procedure are
  - Peripheral oxygen saturation
  - ECG
  - Blood pressure measurement
- The bronchoscopy stack has to be tested and all necessary instruments have to be available (see Fig. 3.1).
- Increasing the FiO_2 to 100% in ventilated patients or increasing the O_2 flow in spontaneously ventilating patients helps minimize the risk of complications associated with hypoxemia.
- Patients not intubated and ventilated should be kept nil-by-mouth for 4 h prior to the procedure.
- Any clotting abnormalities should be corrected in patients where an intervention is anticipated.
- Patients have to be sedated enough to be comfortable during the procedure. Cases where neuro-muscular blockade is used have to be done under general anesthesia (see Chap. 1).

Positioning

The patient should be positioned at a 45° angle to minimize the risk of aspiration whenever possible.

Anatomy

The anatomy of the lower airways is demonstrated in Fig. 3.2. Negotiating the upper airways is obviated in intubated patients. Thus the first recognizable anatomical landmark is the D shaped trachea. This consists of anterior cartilaginous rings and a posterior membranous portion. Direct extensions of the main carina are the left and right

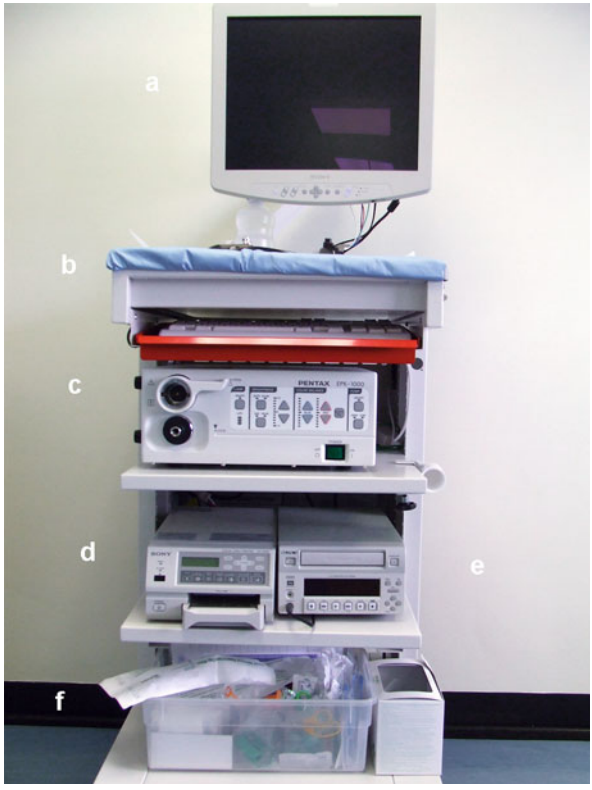


FIGURE 3.1 Typical bronchoscopy stack with (**a**) high resolution screen, (**b**) clean surface for bronchoscope and further instruments, (**c**) light source, (**d**) printer, (**e**) DVD burner, (**f**) storage space for ancillary equipment

main bronchi (see Fig. 3.2a). These tapering structures divide and provide the secondary airways.

The left the main bronchus is angulated and divided into two by a secondary carina. This separates the left upper lobe and left lower lobe (see Fig. 3.2b). The left upper orifice divides into the left upper lobe and lingula. Beneath this is the orifice of the left lower lobe.

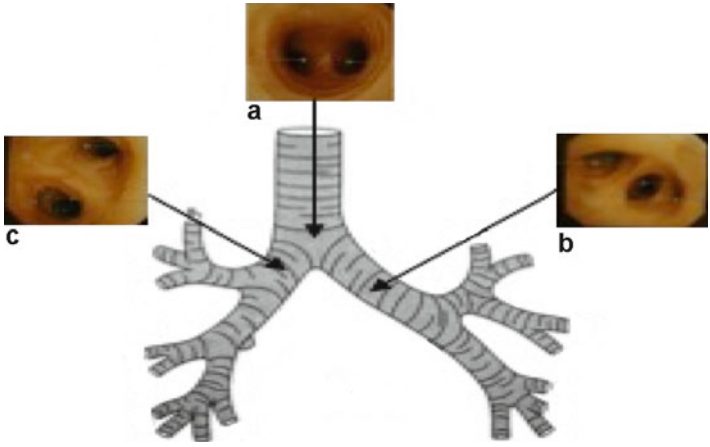


FIGURE 3.2 Bronchoscopic bronchial anatomy, (**a**) view of the carina, (**b**) left main bronchus, (**c**) bronchus intermedius

On the right about 2 cm from the main carina, the right main bronchus divides to the right upper lobe bronchus and the bronchus intermedius.

The orifice of the right upper lobe bronchus is at 90° to the right main bronchus. This trifurcates to the posterior, anterior and apical segments. Beneath this the bronchus intermedius divides into the middle lobe bronchus and the lower lobe bronchus (see Fig. 3.2c). The apical segment of the right lower lobe is opposite to the right middle lobe.

Procedure

- Mechanically ventilated patients will need an adapter on the end of endotracheal tube (ETT) to permit ventilation and access with the flexible bronchoscope simultaneously.
- Prior to the insertion of the bronchoscope the ETT has to be fixed in position by an assistant to prevent displacement during the procedure.
- The bronchoscope should be well lubricated to facilitate the passage through the ETT.

- In non intubated and ventilated patients topical lignocaine 2% (typically up to 10 mL) can be instilled into the central airways.
- Inspection of the airways should be carried out in a systematic manner. If infection is suspected then the infected side should be examined last to reduce cross contamination.
- The position of the ETT has to be checked as the bronchoscope is withdrawn to ensure it is in the correct position.
- Patients who required an airway intervention will usually have a post procedure chest X ray

Diagnostic Interventions

- Broncheo-alveolar lavage (BAL) – the bronchoscope is wedged in a sub segmental bronchus and between two and six aliquots of 20 mL of normal saline are instilled and gently withdrawn by suction. The returned fluid is collected in a sterile receptacle. Lavage volume of 60 mLs are adequate for proximal airway sampling, alveolar sampling requires 60–120 mL. The samples obtained in this way are guaranteed to be from the lower airway and can be analyzed for a variety of diagnostic tests.
- Brushing – bronchial brushing allows the collection of exfoliated airway cells, which can be examined cytologically. This technique is most useful in cases of suspected malignancy.
- Biopsy - endobronchial biopsy allows the mucosa of the main airways to be histologically examined. This is particularly useful diagnostic tool for mucosal processes, such as
  - Bronchial carcinomas and sarcoidosis
  - PCP and fungal infection
  - Post transplant rejection.

In ventilated patients transbronchial biopsies of the small airways and associated lung parenchyma carry an increased risk of pneumothorax and bleeding. It is therefore essential to perform a chest X-ray post procedure.

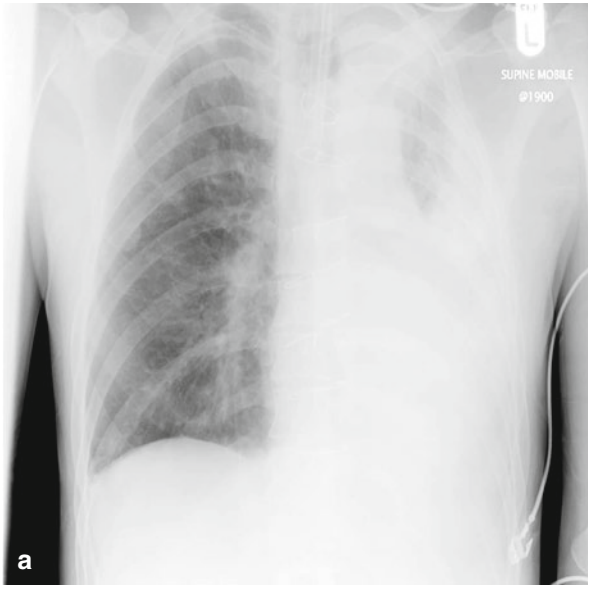
Therapeutic Interventions

- Bronchial toilet and removal of obstruction – atelectasis is a common problem in mechanically ventilated patients. This frequently causes collapse and consolidation with subsequently impaired gas exchange. Relieving any obstruction not only improves radiological appearance (see Fig. 3.3) but also can markedly improve respiratory function and the overall clinical picture.
- Hemoptysis – massive hemoptysis is defined as the coughing up of >400 mL of blood in 24 h or >200 mL in any single event. Fibre-optic bronchoscopy and radiologic imaging are important in diagnosing the cause and localizing the site of hemoptysis. Besides the appropriate measures of resuscitation, a FOB should be performed as early as possible after the event in order to obtain the most useful information. Therapeutic interventions at the time of inspection of the airway, such as diathermy to tumors, may alleviate any on-going bleeding. If there is identifiable ongoing bleeding, isolation of the affected side by balloon tamponade can protect the healthy airways from aspiration of blood.

Complications

FOB is a very safe procedure and complications are fortunately rare.

- Some previously non-ventilated patients might require intubation and a brief period of ventilation post procedure.
- Local problems, such as vocal cord dysfunction, are usually transient and do not need specific management.
- The development of arrhythmias is usually transient but may require short- term anti-arrhythmic treatment.
- Fever associated with FOB is mostly short lived but may persist and require antimicrobial treatment.
- Bleeding after biopsies is often manageable with topical application of 5 mL of adrenaline 1:10000 and/or cold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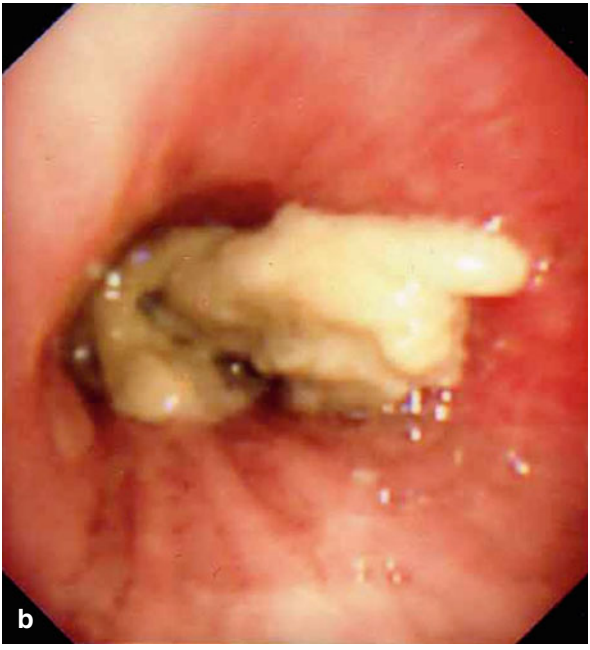
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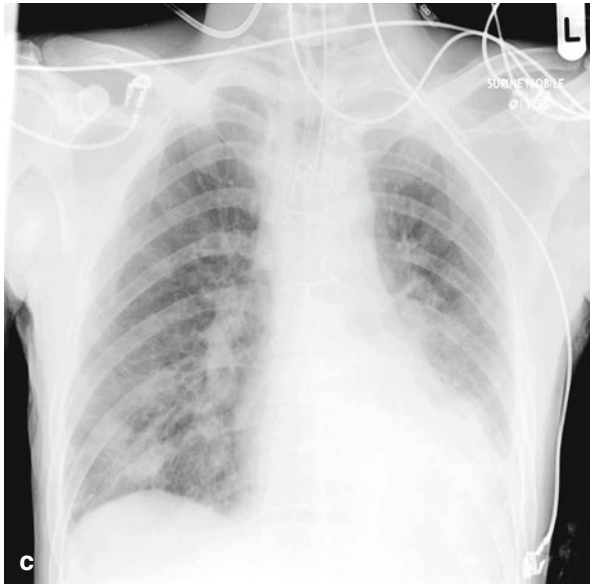

FIGURE 3.3 (continued)

saline. If this fails to stop the bleeding, radiology and thoracic surgery should be involved as early as possible.

- Most post biopsy pneumothoraces can be managed conservatively. The clinical picture should direct insertion of a chest drain (see Chapt. 10).

FIGURE 3.3 (**a**) Chest X-ray demonstrating left lung collapse due to airway obstruction, secondary to (**b**) retained mucus plug, (**c**) post plug removal CXR showing resolution of collapse

Chapter 4
Percutaneous Dilatational Tracheostomy

Robert Martynoga and Chris Danbury

Tracheostomy is a surgical procedure commonly performed in critically ill patients. Formerly, the majority of tracheostomies were performed in the operating theatre mainly by head-and-neck surgeons. However, since Ciaglia et al. introduced percutaneous dilatational tracheostomy (PDT) in 1985, many intensive care physicians consider it to be a core procedure, suitable to be performed at the bedside. PDT offers several advantages over a surgical technique, including

- Avoidance of transfer of the critically ill patient
- Reduced waiting time for theatre availability after the indication has been made
- Formation of a tight stoma with a snugly fitting tube, thereby reducing the risk of bleeding

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- Lower rate of wound infections
- The smaller incision usually resulting in a cosmetically more acceptable scar.

PDT has been demonstrated to be a safe procedure in many difficult patient groups, including the obese and those with refractory coagulopathy. Studies have shown cost-savings relative to surgical tracheostomy.

On the other hand, PDT has been associated with a higher rate of accidental decannulation and obstruction.

Indications

- Weaning from mechanical ventilation
- Weaning from sedative medication
- Long-term airway maintenance
- Need for bronchial toilet

It is important to note that PDT is an elective procedure and has no role in emergency airway control.

Contra-Indications

Absolute

- Age <8 years
- Severely abnormal anatomy of the neck
  - Hematoma
  - Tumor
  - Thyromegaly

Relative

- Difficult anatomy (apart from above)
- Infection or malignancy at or near the proposed site
- Unstable cervical spine fracture

- Severe coagulopathy
- $FiO_2 > 0.6$ and/or PEEP > 10 cmH_2O

Consent

Best practice dictates that every effort should be made to obtain informed consent from the patient prior to any surgical procedure. However, many ICU patients are unable to participate in any decision due to the nature of their critical illness and any sedative drugs they may have received. In this situation it is highly appropriate to fully explain the procedure and its risks and benefits to the patient's relatives. Patients or relatives should be made aware of the following potential complications:

- Bleeding
- Pneumothorax
- Infection

Preparation

- Where appropriate any coagulopathy and platelet defect should be corrected.
- PDT is not a procedure for a single operator. The team has to comprise of
  - One operator for the PDT
  - One endoscopist, who is also proficient in airway management and manipulation, for the bronchoscopy.
  - One support staff (often a nurse), familiar with the equipment and the procedure.
- Immediate availability of airway equipment is mandatory (see Chap. 2), as urgent orotracheal re-intubation may be required.
- Adequate lighting is essential.
- An appropriate selection of different sized tracheostomy tubes needs to be available. It is recommended to have one size up and one size down as well as the desired size at the bedside.
- The necessary instruments and the procedure kit (see Fig. 4.1) need to be laid out sterile on a procedure trolley.

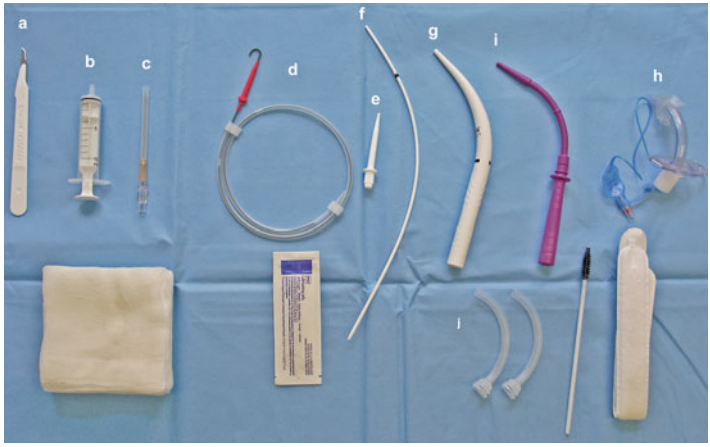

FIGURE 4.1 Pre-packed procedure kit for PDT (**a**) No 15 blade, (**b**) 10 mL syringe, (**c**) 14G needle with cannula, (**d**) guidewire, (**e**) 14 Fr short dilator, (**f**) sleeve for guidewire, (**g**) single stage tapered dilator, (**h**) tracheostomy tube, (**i**) tube introducer, (**j**) inner cannulas

- The bronchoscopy stack with a large screen needs to be placed so that every member of the team can follow the procedure.
- The patient needs to have a general anesthetic, including neuro-muscular blockade (see Chap. 1), and needs to have adequate monitoring, including capnography.
- To reduce the risk of severe hypoxia patients should be ventilated with a $FiO_2 = 1$ for several minutes prior to starting the procedure.
- Many operators will infiltrate local anesthetic (1% lignocaine with 1:200,000 adrenaline is appropriate) under aseptic conditions. Approximately 10 mL should be deposited in the subcutaneous tissues and deeper structures.
- PDT is a clean procedure, performed under aseptic conditions. The operator should scrub and wear hat, mask and sterile gown and gloves. Suitable eye protection is strongly recommended.

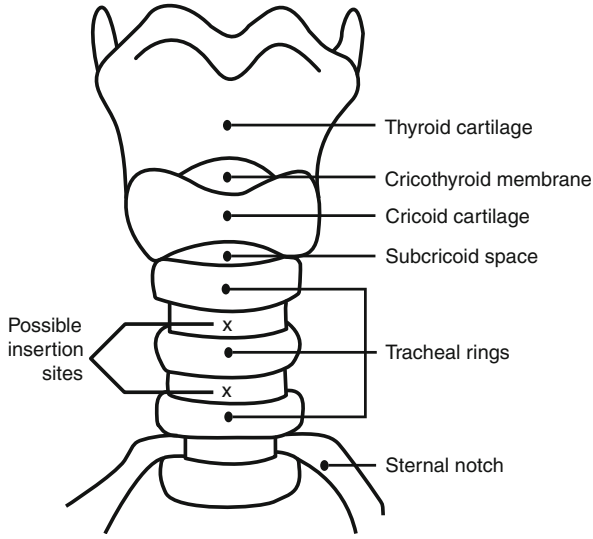

FIGURE 4.2 Anatomy of the neck and incision site for tracheostomy

Positioning and Identification of Site

- The patient is positioned supine with the neck slightly extended – placing a rolled towel or bag of fluids under the shoulders and removing the pillow is usually sufficient.
  - Over-extension of the neck can result in a low tracheal puncture and a tracheostomy too close to the supra-sternal notch.
- The operator has to identify the landmarks of the anterior neck, confirming the midline positions of the thyroid cartilage, crico-thyroid membrane, cricoid cartilage, proximal trachea and supra-sternal notch (see Fig. 4.2). Note should be taken of any other anatomical features which are important to avoid, such as visible anterior jugular veins or the isthmus of the thyroid.

Procedure

Once set up is complete, the patient's neck is prepared with an antiseptic solution and draped. At this point the endoscopist starts the procedure:

- The ETT cuff is deflated and carefully withdrawn under direct laryngoscopic vision until the re-inflated cuff rests just above the vocal cords in the larynx. Downward pressure might have to be applied to the ETT to seal a possible air leak.
- The bronchoscope is inserted into the endotracheal tube (ETT) and advanced into the trachea.
- The bronchoscope is positioned at the tip of the ETT in order to visualize as much of the trachea as possible. This position should be maintained throughout the procedure to allow confirmation of safe tracheal puncture and correct placement of the tracheostomy.

The operator then proceeds as follows:

- A small horizontal skin incision is made over the second or third tracheal ring. This is followed by blunt dissection with artery forceps to the pre-tracheal fascia. Applying firm pressure can normally stop bleeding.
- Once the tracheal rings are palpable with a fingertip, transillumination from the bronchoscope should be visible. Extrinsic compression of the trachea is generally visible in the bronchoscopic view.
- Needle and cannula are introduced midline and almost vertically, pointing slightly caudally. Advancing the needle under continuous aspiration will clearly indicate tracheal puncture when air is drawn back (see Fig. 4.3).
- If the trachea is not punctured at the depth expected the needle has to be withdrawn. A new attempt should only be undertaken after thorough re-palpation and renewed identification of the relevant anatomical structures. Multiple stabs increase the risk of puncturing neighbouring structures.
- A bronchoscopically visualized puncture at the 11 o'clock to 1 o'clock position is reassuring and will allow the cannula to be advanced into the lumen without injuring the posterior tracheal wall.

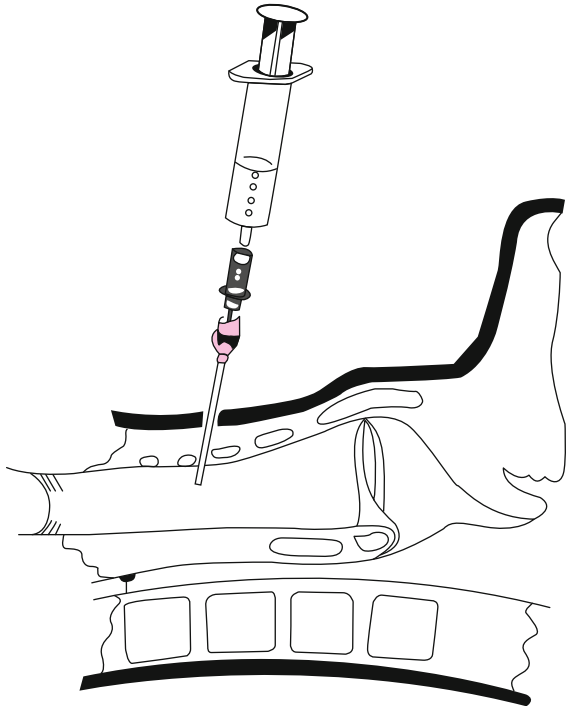

FIGURE 4.3 Ideal needle position in the tracheal lumen: central in the trachea, angled slightly caudally (Reproduced with kind permission from Smith Medical)

- Next the guidewire is advanced into the cannula (see Fig. 4.4), again confirming intra-luminal placement with the bronchoscope. A "hold-up" will be felt as the tip of the wire enters a more distal bronchus.
- A small short dilator is passed into the trachea and immediately removed again, followed by the sleeve for the guidewire, which is left in situ. Again this has to be visualized bronchoscopically.
- The tapered dilator is advanced in a firm downward motion with rotation to follow the curvature of the wire. The bronchoscopic view is crucial to ensure pre-tracheal dilation does not occur. Avoiding any twisting motion, the

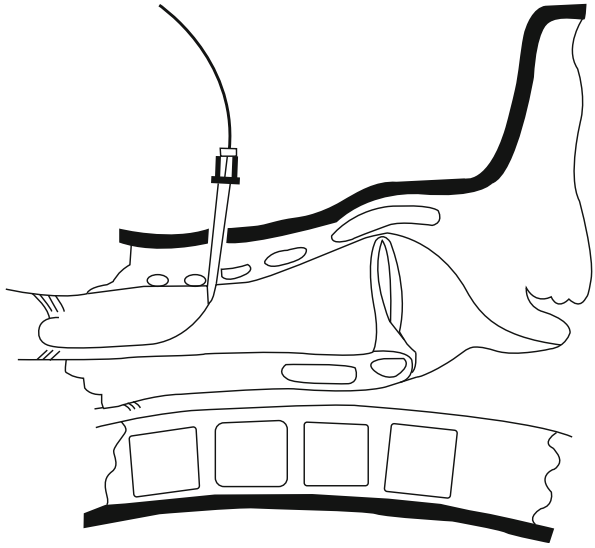

FIGURE 4.4 Guidewire in the tracheal lumen (Reproduced with kind permission from Smith Medical)

dilator should advance smoothly to the marked depth. Once in that position it should be held in place for 10 s, accepting that ventilation will not be possible in this time. The dilator has to be removed carefully, ensuring that the wire is left in situ.

- Following that the tracheostomy tube, mounted on its introducer, is passed into the trachea over the wire (see Fig. 4.5). Resistance is often felt as the cuff passes into the lumen. Once the position of the tube has been confirmed with the bronchoscope, the introducer and wire can be removed.
- The bronchoscope is passed down the new tracheostomy to confirm intra-luminal placement.
- The inner tube is placed in the tracheostomy tube and the ventilator tubing is connected. Bilateral chest movement and capnography have to be observed.
- Lastly, the new tracheostomy tube is secured with suitable tapes, ties or can be sutured.

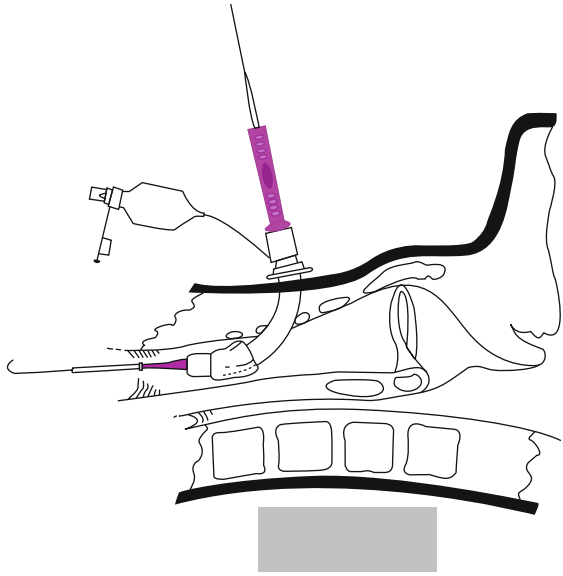

FIGURE 4.5 Feeding the tracheostomy tube into the trachea over the guidewire (Reproduced with kind permission from Smith Medical)

Following the procedure the patient has to be closely monitored for possible complications, especially if difficulties with the tracheal puncture or dilatation have occurred. In most units a portable chest X-ray is performed to exclude a pneumothorax, although it has been suggested that this may not be mandatory where placement has been uncomplicated and visualized bronchoscopically. Once neuromuscular blockade has faded, sedation can be lightened.

Common Complications

- Bleeding from the venous system of the anterior neck is commonly encountered. While obvious large veins will be avoided during the procedure, smaller ones may be torn during dilation. Firm pressure will usually be sufficient to

stop bleeding from these small veins. The introduction of the tight-fitting tracheostomy tube will further compress any injured vessels. Hemorrhage into the airway is potentially serious as blood clots may cause airway obstruction. Catastrophic bleeding can occur if great vessels are lacerated during overly forceful dilatation. This requires immediate emergency exploration of the neck.

- A pneumothorax can be caused by making several passes with the initial needle or if the trachea is not punctured in the midline. As a pneumothorax may not become clinically apparent for some time, an early chest X-ray may be falsely reassuring. Pneumomediastinum and surgical emphysema are possible complications after initial difficulties identifying the trachea with the needle.
- Early accidental decannulation is likely to require swift oro-tracheal intubation. In the first few days after formation the tract will be immature and the tissues may close in if the tracheostomy tube is removed. Attempts at re-insertion, especially in an emergency situation, are liable to create a false tract, with the risk of hypoxia and death. It is far safer to undertake a rapid sequence induction and orotracheal intubation. An occlusive dressing can be placed over the tracheostomy site until the tract can be re-established.
- Infection is a possibility with any tracheostomy, where the respiratory tract exits directly to the skin. Local cellulitis, abscess or ulceration may develop. The treatment options for infections range from anti-microbial therapy to surgical debridement.
- Clinically significant subglottic stenosis has a low incidence following percutaneous tracheostomy. Injury to cartilaginous tracheal rings may occur, but these usually remodel after decannulation and have little long-term significance. Factors thought to be associated with the development of tracheal stenosis include mucosal ischaemia and edema due to the pressure exerted by endotracheal tube cuff, especially with prolonged intubation.
- The small horizontal incisions associated with the percutaneous method are usually associated with smaller, neater

scars than those left following formal surgical tracheostomy with a vertical incision.

- Tracheo-esophageal fistulae are rare but may develop either following trauma to the posterior tracheal wall or as a late complication, mainly due to erosion by an ill-fitting tracheal tube.
- Fiber-optic bronchoscopes are expensive, and fragile. Care should be taken to keep the tip within the ETT to help prevent damage from the needle occurring.

Chapter 5
Arterial and Venous Catheter Insertion

Stephen Webb and Gordon Mijovski

Vascular cannulation is one of the most common procedures in any Intensive Care Unit. Indwelling vascular catheters are used for multiple diagnostic and therapeutic purposes.

Consent

In non-sedated, conscious patients the procedure should be explained and consent obtained.

Arterial Cannulation

Invasive arterial blood pressure measurement allows continuous readings of the arterial pressure waveform. This has become standard hemodynamic monitoring in numerous clinical situations including

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- Hemodynamic instability
- Failure to use non-invasive techniques
- Therapeutic interventions in the cardio-vascular system

Arterial catheters provide convenient access to obtain blood samples for multiple blood gas analyses.

The most common site for arterial cannulation is the radial artery. In circumstances where this is impossible or contraindicated (e.g. site infection, burns) other sites can be used: femoral, doraslis pedis, ulnar, brachial or axillary artery.

Preparation

A pack containing the necessary components should be laid out on a procedure trolley (see Fig. 5.1). Aseptic technique must be employed throughout. The operator should use sterile gloves. For skin preparation 2% Chlorhexidine has been recommended.

The operator needs to ensure that the transducer system is set up and the monitor is calibrated prior to starting the procedure. Regardless of the site or the technique used, awake patients should be given local anesthesia (usually 1–3 mL lignocaine 2%) once the site for cannulation has been identified.

Generally the initial approach to cannulation is at a steeper angle, about 45°. Once the vessel has been identified, the needle is lowered to a shallower 30° before inserting the cannula or guide wire (see Fig. 5.2). This helps to avoid injury to the back wall of the artery.

Technique

The different approaches described below are for radial cannulation, but apply in principle to all cannulation sites. Three different techniques are widely used: catheter over needle with or without transfixing the artery and catheter over wire.

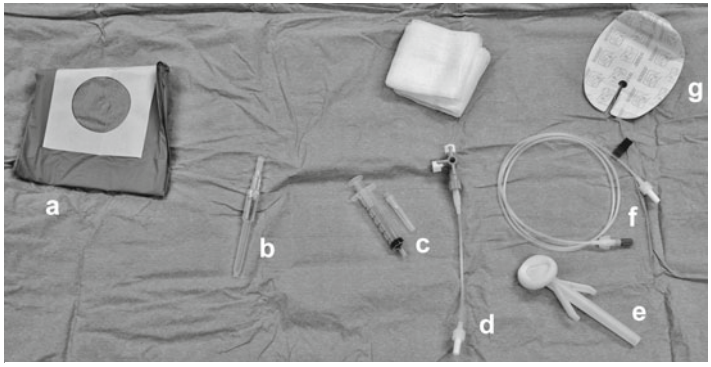

FIGURE 5.1 Procedure trolley for arterial line insertion: (**a**) sterile drape, (**b**) 20G cannula, (**c**) syringe and needle for local anesthetic, (**d**) extension and three way tap to connect to cannula, (**e**) dispenser with skin prep, (**f**) extension to transducer, (**g**) sterile dressing

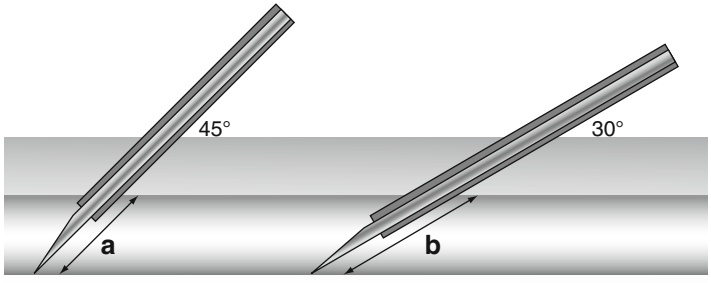

FIGURE 5.2 Recommended approach to arterial cannulation: (**a**) initial steeper angle, (**b**) shallower angle for insertion of cannula or guide wire

Catheter over Needle Without Transfixing the Artery

- Support the wrist and immobilize it in slight dorsiflexion.
- Palpate the artery, infiltrate with local anesthetic.

- The catheter over needle unit is advanced at the site where the strongest pulse can be felt at an angle shallower than 45° angle in short, quick movements, aiming for the middle of the artery.
- When backflash appears lower the unit to 30° and slightly advance it.
- Advance the catheter only using rotational movements.
- Connect to extensions, make sure lines are completely free of any air, check that arterial line aspirates easily and flush with saline 0.9%.
- Connect transducer to monitor and check trace.

The key to a successful cannulation with this technique is not to pass the tip of the cannula through the posterior wall of the artery. This is facilitated by using a low angle of insertion which will allows enough length of the needle bevel to enter the artery lumen without damaging the posterior wall.

Catheter over Needle with Transfixing the Artery

This technique may be used in patients where difficult cannulation is anticipated.

- Support the wrist and immobilize it in slight dorsiflexion.
- Palpate the artery, infiltrate with local anesthetic.
- Apply slight pressure on the artery in order to immobilize it before advancing the catheter over needle unit.
- The unit is advanced at a 45° angle in one long, quick movement, aiming for the middle of the artery.
- Relieve the pressure off the artery and withdraw the needle within the catheter to a level above the skin.
- Start slowly withdrawing the catheter until backflash appears.
- Slightly advance the needle within the catheter to provide stability to the catheter before advancing it
- Using rotational movements, advance the catheter in the artery.

- Connect to extensions, make sure lines are completely free of any air, check that arterial line aspirates easily and flush with saline 0.9%.
- Connect transducer to monitor and check trace.

The key to a successful cannulation with this technique is to apply slight pressure on the artery. This not only immobilizes it, but also increases the actual diameter of the artery as the anterior and posterior wall are brought parallel to each other before advancing the needle catheter unit.

Catheter over Wire (Seldinger Technique)

- Support the wrist and immobilize it in slight dorsiflexion.
- Palpate the artery, infiltrate with local anesthetic.
- A needle is advanced at an 30–45° angle in short, quick movements, aiming for the middle of the artery until back-flash appears.
- After a pulsating back flow appears the wire is introduced gently.
- Remove the needle once the wire is in the artery. The catheter is threaded onto the wire and advanced into the vessel over it, after which the wire has to be withdrawn.
- Connect to extensions, make sure lines are completely free of any air, check that arterial line aspirates easily and flush with saline 0.9%.
- Connect transducer to monitor and check trace.

Arterial Cannulation in Presence of Pulseless Flow

Arterial cannulation in patients supported with pulseless mechanical circulatory support devices or veno-arterial extracorporeal membrane oxygenation may be difficult. Using ultrasound guidance in this setting is strongly recommended.

Arterial Cannulation During Severe Hemodynamic Instability or CPR

Peripheral arterial access can be very challenging in these situations. Rather than spending precious time with numerous attempts, rapid cannulation of the femoral artery using the Seldinger technique is recommended. An additional advantage is that the femoral pressure corresponds better with the aortic pressure during low output states.

Complications

- Hematoma is not uncommon, particularly when the artery is transfixed and after multiple or traumatic attempts at cannulation. To avoid damage to adjacent structures any hematoma has to be prevented from spreading with a tight dressing, while closely monitoring distal perfusion.
- Distal embolization of clot or air occurs rarely and can be avoided by careful catheter care and observation. The treatment follows the principles of treating arterial thrombosis.
- Inadvertent injection of drugs is a serious complication that can be avoided by clear labeling of all ports. Generally the cannula has to be left in place to allow treatment. The treatment depends on the drug injected but can vary from flushing with saline 0.9%, injection of papaverine or procaine to sympathetic block of the limb. Analgesia and anticoagulation are normally required.
- Disconnection of the line can lead to subsequent hemorrhagic shock and massive transfusion requirements. Careful catheter care and no more connections than absolutely necessary help avoiding this potentially life-threatening complication.
- Vascular thrombosis or spasm can be avoided by using catheters that are appropriately sized for the vessel. The larger the artery and the smaller the catheter, the fewer complications tend to occur.

Central Venous Catheterization

Indications

Central venous catheters (CVCs) are the mainstay of fluid management, intravenous medication, electrolyte administration, parenteral nutrition and central venous pressure monitoring.

CVCs are manufactured with up to five separate lumens. The operator has to make sure that a catheter with enough access is inserted to fulfill its therapeutic and monitoring functions.

Contraindications

- Infection at catheterization site
- Venous thrombosis at catheterization site

Relative Contraindication

- Coagulopathy or therapeutic anticoagulation. It is recommended to choose a site that can easily be compressed (e.g. internal jugular or femoral, avoid subclavian) and use ultrasound guidance.

Preparation

The patient has to be monitored with continuous ECG throughout the procedure.

Aseptic technique must be employed. The operator should scrub and wear gloves, gown, mask and hat. For skin preparation 2% Chlorhexidine has been recommended, the cannulation site has to be generously draped. A procedure trolley with all necessary equipment and the catheter should be

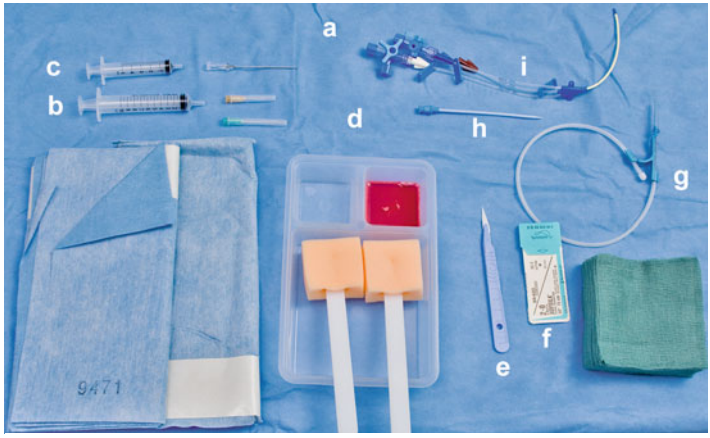

FIGURE 5.3 Procedure trolley for central vein insertion: (**a**) sterile drape, (**b**) syringe and needle for local anesthetic, (**c**) needle and syringe for puncture, (**d**) tray with skin prep, applicators and NaCl 0.9% to flush, (**e**) scalpel, (**f**) suture, (**g**) guidewire, (**h**) dilator, (**i**) 3-lumen central venous catheter

prepared and placed within easy reach of the operator (see Fig. 5.3). The cannulation site should be infiltrated generously with local anesthetic (usually 5 mL lignocaine 2%).

When using the subclavian or jugular site, the patient has to be positioned in slight Trendelenburg position to avoid air embolism and increase the vein diameter. The femoral access demands the opposite i.e. slight anti-Trendelenburg position.

Cannulation Sites

Most commonly used for ventral venous cannulation are:

- Internal Jugular vein
- External jugular vein
- Subclavian vein
- Femoral vein.

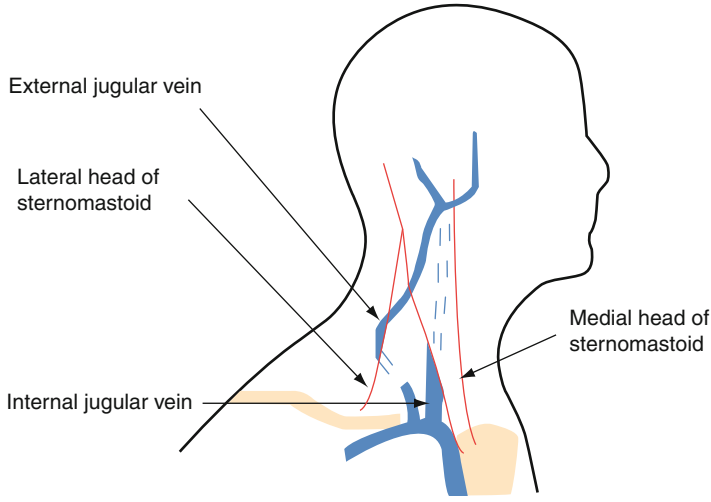

FIGURE 5.4 Anatomy of the internal and external jugular vein

Internal Jugular Vein

The anatomy of the internal jugular site allows cannulation with a number of different approaches (see Fig. 5.4):

- Central - the apex of the triangle formed by the lateral and medial head of the sternocleidomastoid muscle is the insertion point of the needle. The needle should be advanced caudally and laterally towards the ipsilateral nipple. With the central approach, the right internal jugular vein is at its most superficial position and the needle should not be advanced for more than 1.5–2 cm to avoid perforating the pleura.
- Anterolateral - the medial border of medial head of sternocleidomastoid muscle halfway between the mastoid process and sternoclavicular joint is the insertion point. The needle should be advanced caudally and laterally towards the ipsilateral nipple. Unlike the central approach, the anterolateral approach is useful for cannulating the internal jugular vein on both right and left sides. At this level the position of the internal jugular vein in relation to

the carotid artery can vary. It may be posterolateral, lateral or anterolateral to the carotid artery.

- Posterolateral - the lateral border of the lateral head of sternocleidomastoid muscle at the level of the thyroid cartilage is the insertion point. Sometimes it will also be the point where the external jugular vein crosses the lateral border of the lateral head of sternocleidomastoid muscle. The needle is advanced caudally and medially.

External Jugular Vein

The external jugular vein is posterior to the internal jugular vein (see Fig. 5.4) and is often clearly visible, particularly when the patient is in Trendelenburg position. The needle is inserted well above the clavicle and advanced at a shallow angle towards the vein. Despite the easy access external jugular cannulation is not common because the presence of valves can make passing a J-wire difficult or sometimes impossible.

Subclavian Vein

The insertion point is just medial to the mid-clavicular line a finger's depth beneath the clavicle (see Fig. 5.5). A more lateral insertion point increases the risk for arterial puncture, a more medial insertion point makes it more difficult to place the needle under the clavicle. The needle is advanced underneath the clavicle aiming towards and slightly above the sternal notch. Gentle traction of the ipsilateral arm often helps by bringing the vein and clavicle closer together.

Femoral Vein

The femoral vein accompanies the femoral artery together with the femoral nerve through the femoral triangle (see Fig. 5.6).

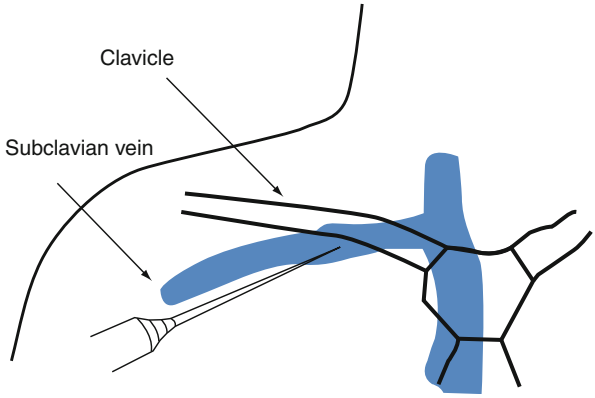

FIGURE 5.5 Anatomy of the subclavian vein

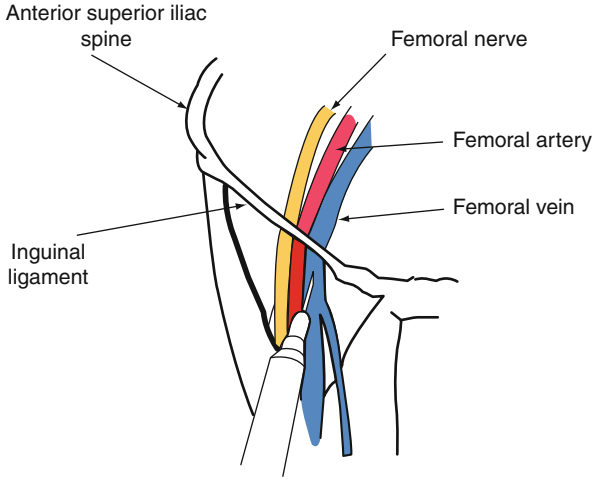

FIGURE 5.6 Anatomy of the femoral vein

For access the patient's leg is extended and slightly abducted at the hip. It is advisable to locate the femoral pulse for anatomical guidance. The needle is inserted about 1.5 cm medial of the femoral artery pulse and 2 cm below the inguinal ligament.

Technique

Whenever possible, central venous cannulation has to be performed under ultrasound guidance. Veins can easily be distinguished from arteries because they

- are collapsible when slight pressure is applied with the US transducer
- don't show pulsatile flow if a Doppler mode is used.

Central venous catheters are almost always inserted using the Seldinger technique.

- The vessel is punctured with a sharp, hollow needle attached to a 5 or 10 mL syringe. While advancing constant negative pressure should be applied by gently pulling the plunger back until blood is aspirated.
- If no blood is aspirated on first pass, withdraw the needle slowly while continuing to apply negative pressure.
- Once blood is aspirated detach syringe to check for blood flow. It is important at that point to immobilize the needle with one hand.
- With the other hand the wire should be advanced through the needle, but only just enough to safely enter the vein.
- After making a small skin incision the dilator is used to dilate the subcutaneous tissue only.
- The catheter is threaded on to the guidewire and advanced into the vascular lumen. The operator has to make sure that the wire is not advanced into the vessel with the catheter and is easy to withdraw once the catheter is in place.
- Flushing all lumens with saline 0.9% immediately helps prevent clotting.
- When securing the CVC to skin, care should be taken to avoid puncture of any adjacent structures.
- A chest X-ray should be taken after a difficult subclavian or jugular line insertion with multiple attempts at one or several sites.

Complications

- Air embolism can be avoided by careful patient positioning, particularly Trendelenburg for jugular or subclavian cannulation.
- Cardiac dysrhythmias are easy to detect with ECG monitoring and are usually caused when the guidewire is advanced too far.
- Injury to adjacent structures (such as arterial puncture, pneumothorax, hemo- or chylothorax, nerve and tracheal injury, cardiac perforation or intestinal injury with femoral approach) can mostly be avoided by
  - using US guidance
  - seeking advice from an experienced operator in difficult cases
  - correctly identifying risk factors like deformities, previous surgery or radiation.
- Injuries have to be diagnosed and treated by the appropriate specialty immediately.
- Systemic or local infection (subclavian <jugular <femoral) may be avoided by using aseptic insertion technique, diligent catheter care and removing catheters as soon as they are not needed anymore. There is no evidence that routine, scheduled changes of central lines decrease the risk of infection.

Pulmonary Artery Catheter (PAC)

Indications

Despite having been controversially debated for some time right heart catheterization is still common in patients with severe cardio-vascular compromise. It is used to

- differentiate between cardiogenic and non-cardiogenic pulmonary edema

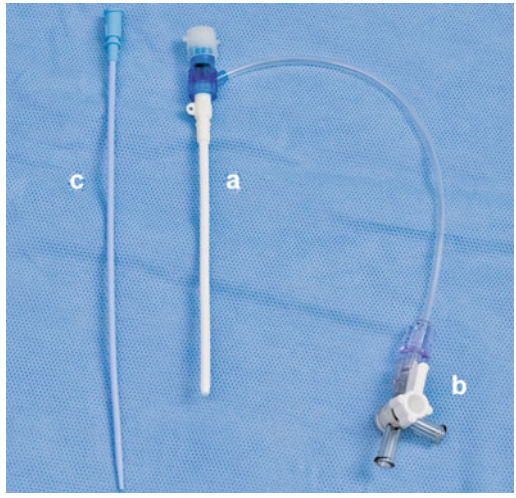

FIGURE 5.7 PAC introducer sheath: (**a**) introducer, (**b**) side arm with 2-way tap, (**c**) dilator

- differentiate between several reasons for hemodynamic instability – such as sepsis, left or right ventricular failure, pulmonary hypertension
- direct therapy with vasoactive and/or inotropic drugs as well as fluid therapy

Preparation

- The PAC introducer sheath (see Fig. 5.7) is placed as described above for CVC. Aseptic technique must be employed throughout. The operator should scrub and wear gloves, gown, mask and hat.

Technique

- Check the balloon integrity by inflating it with 1.5 mL of air.
- Check the lumens are patent by flushing with saline 0.9%.

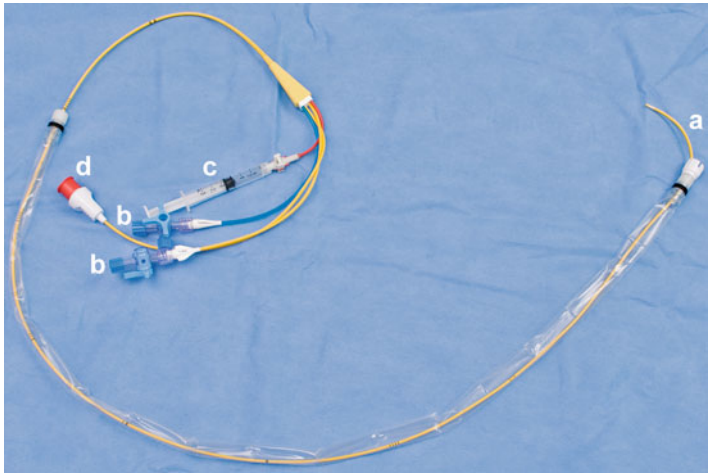

FIGURE 5.8 PAC in sterile sleeve: (**a**) PAC, note markings for depth of insertion in 10 cm increments, (**b**) distal and proximal port, (**c**) syringe to inflate balloon, (**d**) connector to monitor for hemodynamic studies

- Cover the catheter with the sterile sleeve provided (see Fig. 5.8)
- Connect the distal lumen to the pressure transducer.
- Pass the catheter through the introducer with the tip curved towards the heart.
- Once the tip of the catheter has passed through the introducer sheath inflate the balloon.
- The progress of the catheter through the right atrium and ventricle into the pulmonary artery and wedge position can be monitored by the changes of the pressure trace (see Fig. 5.9).
- After acquiring the wedge pressure deflate the balloon

Following a few simple principles helps to avoid some of the complications regularly associated with PACs:

- To assist with advancing with the blood flow, the balloon should be inflated when floating the PAC.
- When withdrawing the PAC, the balloon must be deflated at all times.

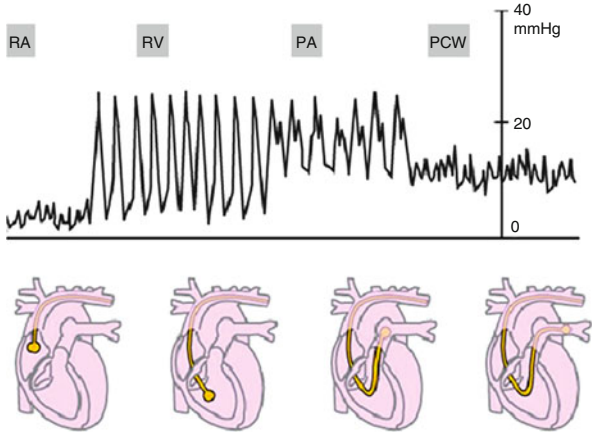

FIGURE 5.9 Pressure traces and corresponding position of PA catheter tip during insertion

- The balloon must never be inflated against resistance to avoid rupture of the pulmonary artery. If wedging occurs before the balloon is fully inflated, the catheter may have migrated distally into the PA. The PAC must be withdrawn to a length where wedging occurs with fully inflated balloon only.

Cardiac Output Measurement

- Connect catheter to monitor and make sure that all parts are compatible.
- During measurement the balloon must be deflated.
- Once the monitor is ready, rapidly inject 10 mL saline 0.9% or 5% dextrose at room temperature.
- CO is calculated by the change of temperature over time on the thermistor in the PA.
- At least three measurements should be taken and the average value calculated.

Complications

Complications seen during insertion of the introducer sheath are similar to those listed for central line insertion. Apart from infection, PAC insertion and maintenance has been associated with a number of potentially severe complications:

- Pulmonary artery rupture has the highest incidence in patients with pulmonary hypertension. The risk can be decreased by avoiding keeping the PAC tip in a distal position and by reducing the number of wedge procedures to a minimum. Depending on the severity of the injury therapeutic options range from stopping anticoagulation and monitoring with serial chest X-rays to positioning the patient laterally with the affected side down, selective bronchial intubation or surgical repair or the ruptured artery.
- Air embolism is mostly caused by repeated attempts to inflate a ruptured balloon. The patient should be given 100% oxygen and ventilatory support as needed and put in a left lateral Trendelenburg position. It can be beneficial to attempt aspirating the air from the right ventricle or atrium while withdrawing the PAC. The principles of BLS and ALS should be followed as necessary.
- Cardiac dysrhythmias are not uncommon during passage through the right heart and can be avoided by minimizing insertion time.
- Tricuspid or pulmonary valve damage is rare. The incidence can be reduced by strictly advancing the PAC only with the balloon inflated and withdrawing only with the balloon deflated. If valve damage is suspected a cardiothoracic surgeon should be consulted.

Chapter 6
Advanced Non-Invasive Hemodynamic Monitoring

Elizabeth E. Turner and Andrew J. Patterson

With the ability to measure parameters such as cardiac output, preload and afterload the pulmonary artery (PA) catheter has been considered the gold standard of hemodynamic monitoring for a long time. In recent years it has partially been replaced by less invasive technologies in many institutions.

When managing hemodynamically unstable patients in the critical care setting, the clinician's goals are:

- Determine the cause of hypotension:
  - hypovolemic,
  - distributive,
  - cardiogenic,
  - obstructive.

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- Decide upon a therapy targeted at the probable etiology of instability:
  - fluids,
  - inotropes,
  - vasopressors,
  - reduce afterload,
  - thrombolytics.
- Reassess the impact of any interventions and make needed adjustments.

Cardiac function is largely determined by

- Preload
- Afterload
- Contractility

Evaluation of Preload

Hypovolemia can be subdivided into two types:

- Absolute hypovolemia is a decrease in circulating blood volume due to hemorrhage or loss of plasma.
- Relative hypovolemia represents the inadequate distribution of an otherwise adequate blood volume in vasoplegic states such as adrenal insufficiency, liver failure, and sepsis.

In both states, the consequence is decreased venous return that ultimately leads to inadequate tissue perfusion.

Whether a patient will be volume responsive depends on the location of their heart on the Frank–Starling curve (see Fig. 6.1).

- Position on the steep portion predicts that an increase in preload will increase stroke volume and cardiac output.
- Position on the flat portion suggests that additional volume will not significantly improve stroke volume or cardiac output and may cause detrimental side effects such as endomyocardial ischemia.

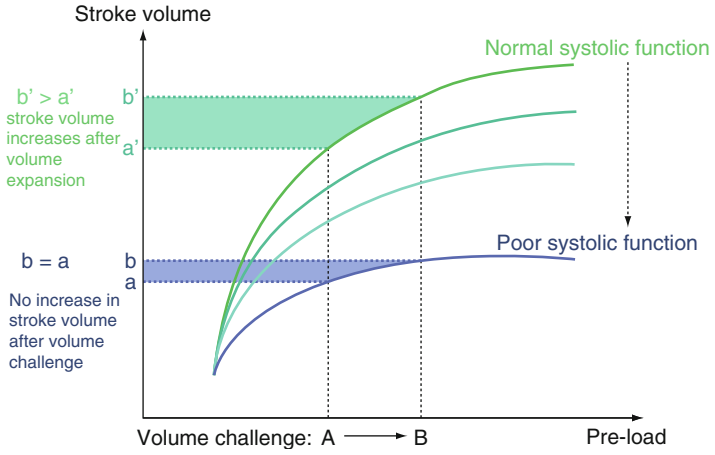

FIGURE 6.1 Frank–Starling curve (Reproduced with kind permission from Ann-Sophie Beraud, Stanford University, www.stanford.edu/group/ccm_echocardio)

The likelihood of a positive response to volume can be assessed using several devices, including transthoracic echocardiography, central venous and arterial catheters.

- Transthoracic echocardiography can be used to predict volume responsiveness at the bedside and to assess the success of interventions.
  - Static measurements have been shown to be less predictive of volume responsiveness when compared to dynamic measurements. However, they still have utility to assess preload.
    - Inferior vena cava (IVC) measurement: In mechanically ventilated and sedated patients, the IVC diameter has a low correlation to fluid responsiveness except at the extremes (<1 cm → likely responder, >2 cm → unlikely responder).
    - A left ventricular end diastolic diameter (LVEDD) of <25 mm suggests decreased preload. This is best

measured using M-mode through a parasternal long axis view across the left ventricle (LV) at the mid-papillary level.
    - A left ventricular end diastolic area (LVEDA) <10 cm^2 measured in the parasternal short axis mid-papillary plane predicts volume responsiveness. However, this measurement is difficult to obtain reliably and accurately.
- Dynamic parameters are more reliable in predicting fluid responsiveness echocardiographically. Increased variability of stroke volume and cardiac output associated with the respiratory cycle signifies variations of preload due to intrathoracic pressure changes (see Fig. 6.2). This variability confirms that the patient's heart resides on the steep segment of the preload/ stroke volume curve.
    - The IVC distensibility index is measured in the subcostal longitudinal view. It describes the relationship between the maximal and the minimal IVC diameter during the respiratory cycle. A value of >18% predicts fluid responsiveness (see Fig. 6.3). This method has been validated in mechanically ventilated and sedated patients in sinus rhythm. It is not reliable in the presence of elevated right ventricular pressures, right ventricular failure, tricuspid regurgitation or intra-abdominal hypertension (see Chapt. 15).
    - A passive leg raise (PLR) to 45° for 1 min provides 300–500 mL "auto-transfusion" in a previously supine patient. A difference of >12% in Delta VTI, Vmax, cardiac output or stroke volume before and after the leg raise predict a >15% increase in stroke volume after fluid resuscitation. PLR has been validated in spontaneously breathing populations as well as in the presence of atrial fibrillation.
    - A small, hypercontractile left ventricle with an estimated or measured ejection fraction (EF) >70% is a good indicator of hypovolemia.
    - More advanced, Doppler based assessment methods require the operator to have significantly more echocardiographic training and experience.

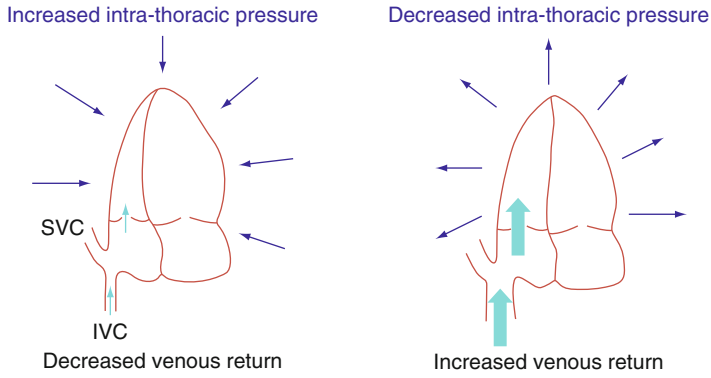

FIGURE 6.2 Respiratory variability of preload (Reproduced with kind permission from Ann-Sophie Beraud, Stanford University, www.stanford.edu/group/ccm_echocardio)

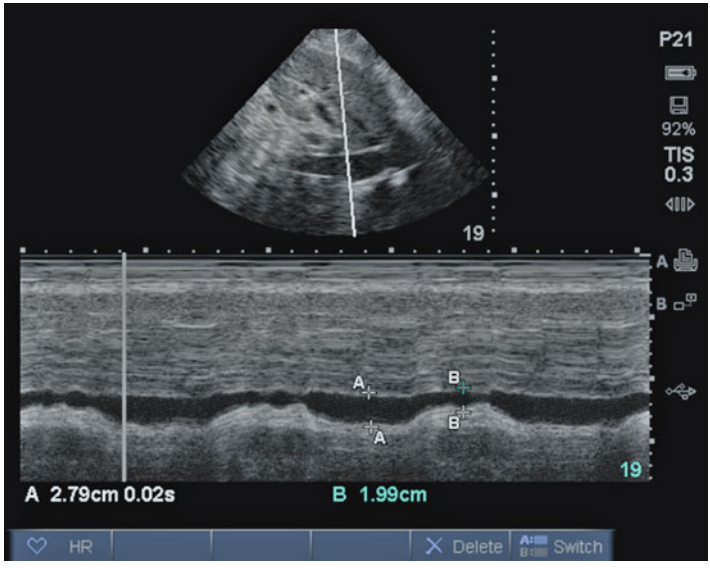

FIGURE 6.3 IVC diameter variability during the respiratory cycle, IVC variability = [(IVC diameter max-IVC diameter min)/mean IVC diameter], a value >18% predicts fluid responsiveness

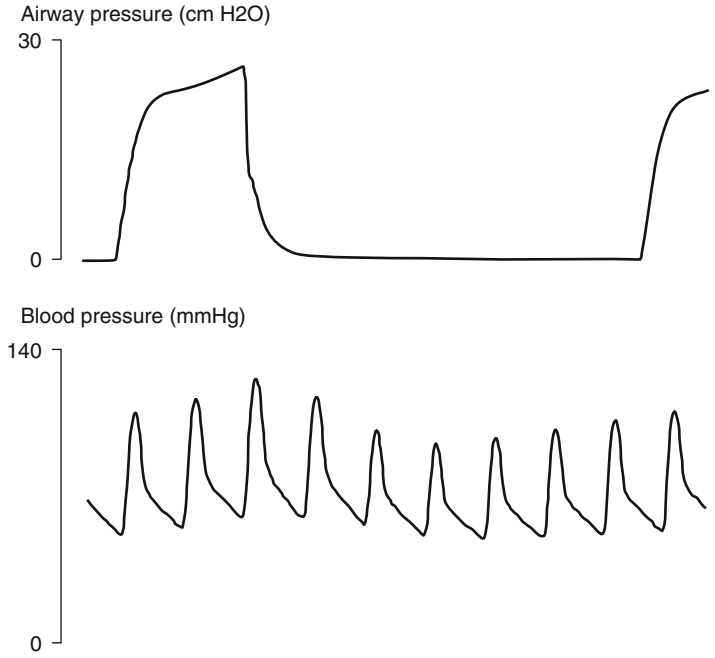

FIGURE 6.4 Respiratory variability of arterial waveform

- Arterial Catheters
  - Arterial waveform baseline variability is a crude but potentially useful marker of a patient's volume state. The degree of variation in systolic pressure over the respiratory cycle during mechanical ventilation is inversely related to intravascular volume. Systolic pressure variation of <5 mmHg indicates a volume replete state (see Fig. 6.4). This method must be used cautiously when predicting volume responsiveness in hemodynamically unstable patients.
  - Arterial pulse pressure is proportional to left ventricular stroke volume. Pulse pressure variability over the respiratory cycle is seen in hypovolemia because changes in preload are determined by intrathoracic pressure.

Table 6.1 Estimated CVP in relation to IVC collapsibility

IVC diameter	IVC % collapse	CVP estimate (mmHg)
<2 cm	>50%	0–5
<2 cm	<50%	5–10
>2 cm	<50%	10–15
>2 cm	None	15–20
>2 cm	None + hepatic vein congestion	>20

This translates into variability in pulse pressure and suggests hypovolemia.

- A strong correlation has been demonstrated between respiratory variation in arterial pulse pressure and respiratory variation in pulse oximeter plethysmography (POP) waveform amplitude. Respiratory variation in POP waveform amplitude >15% correctly identifies patients with significant respiratory variation in arterial pulse pressure due to hypovolemia.

- Central venous catheters
  - Isolated measurement of the central venous pressure (CVP) has been shown to be a poor predictor of preload status. The CVP is easily influenced by extravascular factors such as PEEP, body habitus, chest wall compliance or tricuspid regurgitation.
  - In spontaneously breathing patients the CVP has been correlated with respiratory variability of the IVC diameter. It is generally accepted that a dilated IVC without the typical 50% collapse upon sharp inspiration indicates elevated right atrial pressures. Similarly a small, collapsing IVC marks low right atrial pressures. Table 6.1 shows estimated CVP values in correlation with IVC collapsibility. These measures have been shown to be most reliable and reproducible at the extreme ends of the spectrum.

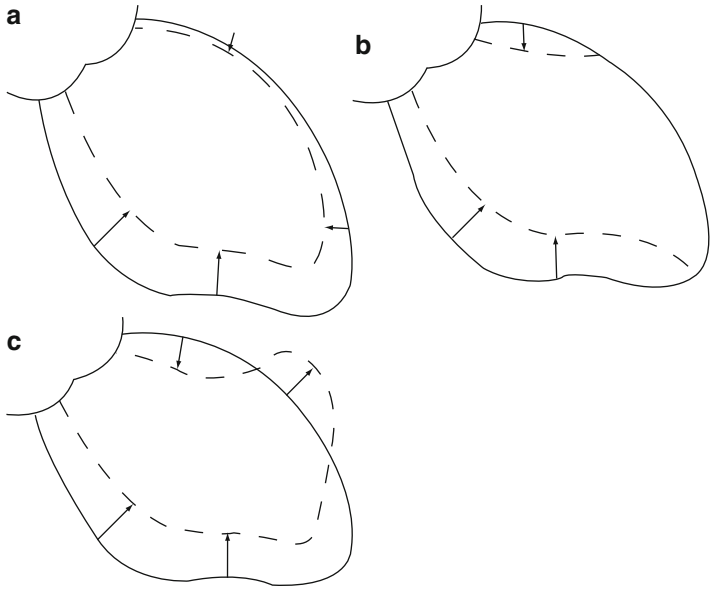

Figure 6.5 Contractile states of the heart, (**a**) hypokinesia, (**b**) akinesia, (**c**) dyskinesia

Evaluation of Inotropic Performance of the Left Ventricle

- Transthoracic echocardiography allows a qualitative assessment of the left ventricle by "eyeballing". With appropriate training and experience an intensivist without formal echocardiography education is able to recognize varying states of left ventricular contractility (see Fig. 6.5) and performance (see Table 6.2).
  - Hypokinesia describes impaired movement.
  - Akinesia describes the absence of endocardial excursion with <10% wall thickening.
  - Dyskinesia describes paradoxical movement during systole.

Table 6.2 Performance states of the left ventricle

Left ventricular performance	Endocardial excursion base to apex (%)	Myocardial thickening (%)	Approximate ejection fraction (%)
Normal	>30	>50	55–70
Mildly reduced	20–30	30–50	40–55
Moderately reduced	20–30	<30	30–40
Severely reduced	<20	<30	<30

Segmental wall motion abnormalities often correlate with coronary artery distributions and may signify an ischemic cause of left ventricular dysfunction.

– Hyperkinesia is typically seen in hypovolemia, elevated catecholamine levels or low afterload states.

Other Common Techniques

- Central venous oximetry catheters can provide continuous monitoring of the central venous oxygen saturation ($ScvO_2$). Delivery of oxygen (DO_2) to tissues is a function of cardiac output, hemoglobin, and oxygen content of the arterial blood. Tissues normally extract around 25% of the delivered oxygen from blood and return hemoglobin 75% saturated to the right heart. In low cardiac output states, tissues must meet their oxygen needs by more efficient uptake. As a result the $ScvO_2$ can be significantly <70% in low output states.
- Tissue oxygen spectrometers measure regional tissue oxygen saturation (StO_2) at the thenar eminence using near infrared spectroscopy. Saturation of hemoglobin at the microvascular level serves as a surrogate for $ScvO_2$. As StO_2 correlates with oxygen delivery and microvascular dysfunction it can help to identify perfusion deficits earlier than lactate or base deficit. It has been shown to be predictive of patient outcome in sepsis.

- Arterial pressure waveform analysis is based on the understanding that pulse pressure is proportional to stroke volume and inversely proportional to vessel compliance. Several devices that attach directly to indwelling arterial catheters are available. By integrating patient demographics they are able to display afterload, stroke volume as well as cardiac index almost continually.
- Bioreactance technology that senses changes in transthoracic electrical signals related to blood flow allows continuous non-invasive bedside evaluation of heart rate, stroke volume, stroke volume variation, non-invasive blood pressure, peripheral resistance, cardiac output and cardiac index.

Additional Considerations

- Lactic acid is the by-product of anaerobic metabolism. Elevated lactic acid levels reflect inadequate delivery or utilization of oxygen at tissue level. In general, anaerobic metabolism decreases in response to increases in oxygen content or delivery. Blood lactic acid levels >5 mmol/L are often associated with under-resuscitation. Correction of lactic acid levels has prognostic implications in shock.
- The base excess refers to excess in the amount of base present in the blood. Acidosis can either be caused by an increased presence of acids (lactic acidosis, ketoacidosis, uremia, etc.) or through loss of bicarbonate. The base excess can be used as a marker of the severity of shock and to evaluate resuscitation efforts. Compared to arterial pH and lactic acid levels, the base deficit has been shown to correct more quickly and to be more specific for hypovolemia during compensated shock. Trauma patients who failed to improve their base excess to <–6 despite resuscitation efforts have an increased incidence of adult respiratory distress syndrome, multiple organ failure and mortality.

Chapter 7
Temporary Cardiac Pacing

Annette van de Sandt and Marc W. Merx

Temporary cardiac pacing may become necessary as treatment or as prophylaxis of hemodynamic instability resulting from tachy- or bradyarrhythmia. The goal is to restore effective cardiac depolarization until the dysrhythmia either can be resolved or until a long-term therapy is initiated.

The transcutaneous and transvenous approaches are most commonly used. Other modalities such as transesophageal pacing or a pacing Swan-Ganz Catheter are unreliable and should not be used in pacing dependent patients.

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Indications

- Symptomatic sinus node dysfunction
  - sinus arrest
  - sinus bradycardia
- Symptomatic atrioventricular (AV) block
  - Mobitz-type II second degree AV block
  - bifascicular block with first degree AV block
  - third degree (complete) AV block
- Symptomatic patient with failed permanent pacing system
- Tachyarrhythmias refractory to medical management

Consent

If not sedated and/or intubated and ventilated the indication, procedure and potential complications associated with temporary cardiac pacing should be explained to the patient and informed consent obtained. Although complications are rare, patients should be made aware of the following:

- Complications associated with central line insertion (see Chap. 5) if the transvenous approach is used
- Failure to place the lead correctly
- Further arrhythmias during lead insertion
- Thromboembolism

Techniques

- Transcutaneous temporary pacing is mostly used as a "bridging" modality in emergency circumstances. Transcutaneous pacing electrodes (self adhesive gel pads frequently also used as defibrillator pads) are usually positioned in an anteroposterior configuration (see Fig. 7.1a) in order to minimize transthoracic impedance. If this configuration is

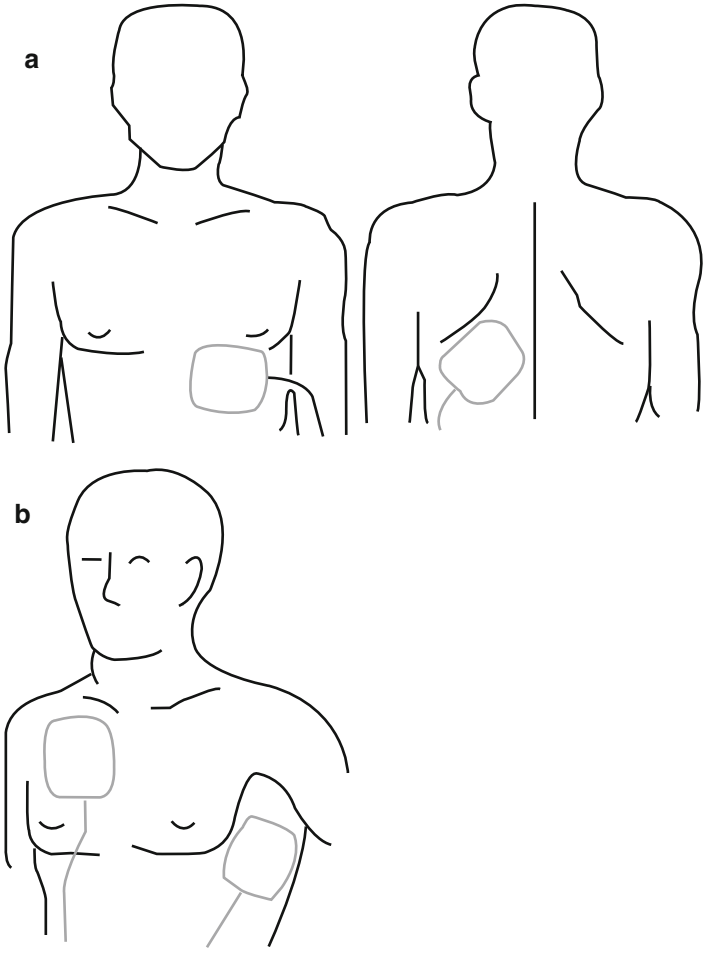


FIGURE 7.1 Position of transcutaneous pacing pads: (**a**) anteroposterior, (**b**) anterolateral

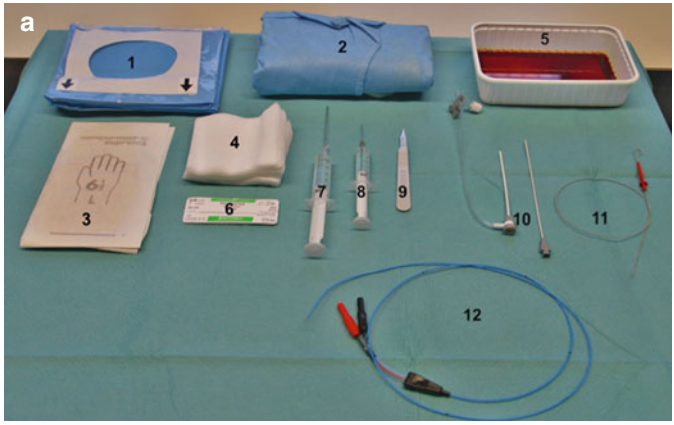
unsuccessful or if electrodes are placed during cardiac arrest, anterolateral placement of pads should be considered (see Fig. 7.1b). Pacing is initiated in an asynchronous mode at maximal output to ensure cardiac capture. A great proportion of patients will experience significant discomfort. If not

sedated and/or intubated and ventilated for other reasons, analgesia or sedation (see Chap. 1) should be considered during transcutaneous pacing.

- Transvenous cardiac pacing is primarily used to correct profound bradycardia and involves the placement of an electrode into the right atrium, right ventricle or both via a central vein.

Preparation

- The following equipment is needed to place a transvenous pacing lead:
  - Generally an introducer set with a hemostatic introducer sheath is used to establish central venous access in a similar way to pulmonary artery catheterization (see Fig. 7.2a). The hub of the introducer needs to be big enough to admit a 5 or 6F pacing electrode.
  - A cable to connect the catheter to the pacemaker.
  - A multitude of pulse generators are available for single and dual chamber pacing (see Fig. 7.2b)
  - Unipolar and bipolar electrodes are available.
    - Unipolar electrodes consist of only one conducting wire and electrode. This means that the electric current returns to the pacemaker via body fluids and a skin electrode. This often causes muscle twitching and discomfort to the patient. Oversensing of muscular potentials can cause problems with pacing inhibition. Unipolar electrodes are rarely used for temporary pacing.
    - Bipolar electrodes have two conducting wires and electrodes surrounded by layers of insulation. The electrical current usually goes along the distal electrode, passes through myocardial tissue causing depolarization and returns to the pacemaker via the second electrode. Inappropriate sensing of skeletal muscular activity is uncommon. Bipolar electrodes are commonly used for temporary endocardial pacing.



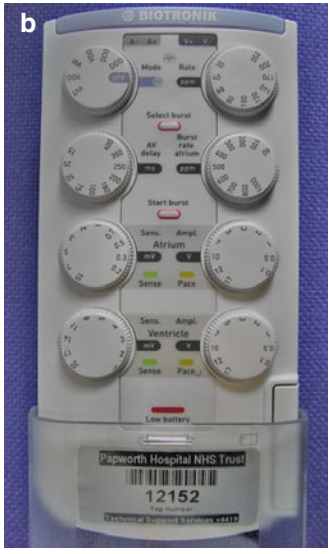


FIGURE 7.2 (**a**) Equipment required for insertion of a temporary transvenous pacing system. (**a**) 1 = fenestrated sterile drape, 2 = sterile gown, 3 = sterile gloves, 4 = swabs, 5 = skin solution prep, 6 = suture, 7 = introducer needle, syringe with flush, 8 = Local anesthetic, 9 = scalpel, 10 = introducer sheath with dilatator, 11 = guidewire, 12 = Bipolar endocardial pacing electrode. (**b**) Typical pacemaker with different modes, atrial and ventricular sensing and output control and LED function indicators

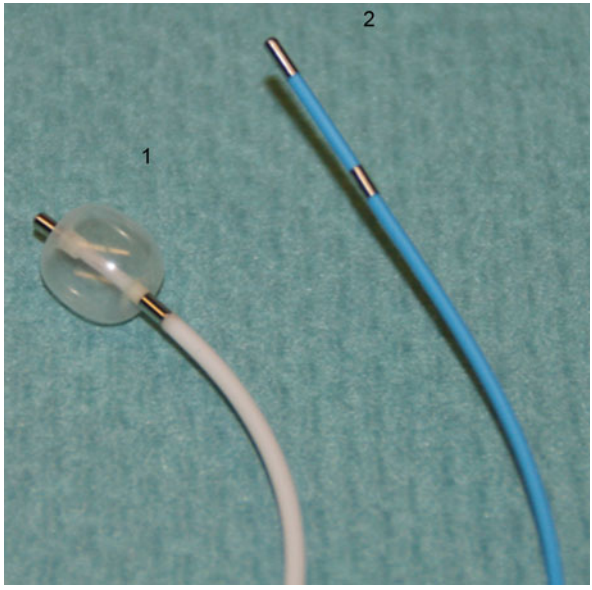


FIGURE 7.3 Types of pacing electrodes: 1 = balloon-tipped bipolar pacing electrode, 2 = bipolar pacing electrode (stiff)

Endocardial pacing catheters vary in stiffness and can be balloon-tipped (see Fig. 7.3). Stiffer electrodes maintain stability over time, but they are potentially more harmful and careful positioning – preferably under fluoroscopy – is needed.

- Ventricular pacing is the mode of choice for temporary pacing because
  - Atrial leads are difficult to position reliably and in a timely manner in an emergency situation and
  - AV conduction abnormalities are amongst the most common indications for temporary pacing.
- Atrial J-electrodes are available for temporary atrial or DDD pacing.

- Continuous electrocardiographic monitoring is recommended during insertion.

- Fluoroscopy is not necessary but is desirable. Under emergency conditions when transcutaneous pacing is not possible, using fluoroscopy will rarely be feasible. In these situations the use of a soft, balloon-tipped catheter may be the safest option.
- Inserting a transvenous pacing system is a clean procedure and should be carried out under aseptic conditions. The operator has to scrub and wear gown, gloves, hat and mask.
- Patients with acute myocardial infarction will often have received thrombolytic or anti-platelet agents. Particular caution is needed during central venous cannulation. Ultrasound guidance is strongly recommended in these circumstances.

Procedure

- Venous access is gained as described in Chap. 5. The choice of route depends on individual experience. For anatomic reasons the left subclavian vein or the right internal jugular vein are most commonly used. The latter has been recommended for its direct route to the right ventricle, potential for the highest rate of success and lowest complication rate.
- Insertion under fluoroscopy:
  - The electrode is advanced until it lies almost vertically in the right atrium. It will usually point to the right towards the free wall. The electrode is rotated between index finger and thumb through 180° until it points downwards and to the patient's left. After crossing the tricuspid valve the electrode should be placed in the right ventricular apex.
  - If difficulty is experienced in crossing the tricuspid valve, the following may help:
    - If hemodynamically stable, remove the lead and reposition the patient with a slight left lateral tilt and head down.
    - Alternatively, form a loop in the right atrium by pointing the electrode tip to the right cardiac border

and then advance the loop across the valve. Once the electrode tip has followed it may require manipulation in the apex to achieve a satisfactory position.

  - Connect the electrode to the pulse generator via the sterile connector cable.

- Blind insertion is usually limited to emergency situations in which transcutaneous pacing is not an option. After venous access has been gained, the pacing catheter is connected to the pacemaker which has the following settings:
  - maximum output,
  - lowest sensitivity,
  - pacing rate 60 and 80 beats/min.
- A left bundle branch block after each pacing spike indicates capture.
- The pacing wire needs to be fixed securely to the skin.
- If the patient has an intrinsic rhythm the sensing and pacing thresholds need to be tested.

Threshold Testing

- Sensing threshold:
  Sensing refers to the ability of the generator to detect and recognize intrinsic activity.
  - The pacing rate needs to be set 10–20 beats/min lower than the patient's intrinsic rate.
  - The millivoltage is decreased until the sense indicator starts flashing regularly with every heartbeat and the pace indicator stops flashing.
  - Next, the millivoltage is increased again slowly until the sense indicator misses individual heartbeats. This is the point at which the sensing threshold is reached. >3 mV is considered acceptable.
  - To provide an adequate safety margin sensing is set at half the value of the sensing threshold.

- Pacing threshold:
  The pacing threshold is the minimum current needed to obtain capture.
  - The pacing rate needs to be set at least 10 beats/min above the patient's intrinsic rate.
  - Starting from the lowest possible setting, the output is slowly increased until pacing captures. At this point the intrinsic stimulation threshold is reached. The ideal pacing threshold is <1 mA. The catheter should be repositioned if >5–6 mA are necessary to achieve capture.
  - Output is set to 2–2.5 times the threshold to ensure safe and consistent capture.

Care of the Temporary Pacing System

- Continuous ECG monitoring is mandatory while a temporary pacemaker is in place.
- A chest X-ray should be obtained as soon as possible after insertion to
  - exclude any complications arising from central venous cannulation,
  - verify the position of the wire. The catheter tip should be visualized at the anterior-inferior aspect of the cardiac shadow (see Fig. 7.4).
- The chest X-ray should be repeated in case of failure to capture or to sense.
- The thresholds and the connections have to be checked regularly. If present, any underlying, intrinsic rhythm should be recorded.
- A 12-lead ECG showing a left-bundle-brunch-block morphology and a superior axis (i.e. upright QRS complex in lead I and aVL) can help confirm the wire position in the right ventricular apex.
- Regular physical examinations may reveal a pericardial friction rub as an early indicator of ventricular wall perforation.

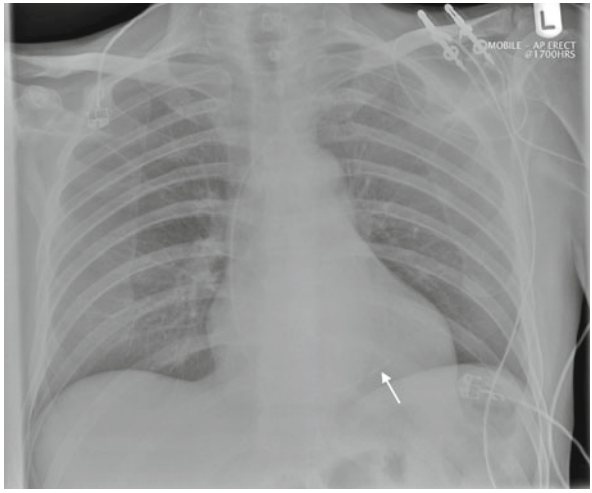


FIGURE 7.4 Chest X-ray with temporary pacing electrode via the left subclavian vein (*arrow*)

- Daily dressing changes are necessary to detect evidence of infection around the site of venous access.

Common Complications

Complications occur in up to 20% of patients with a temporary pacing system in situ. The most commonly seen complications are related to gaining venous access (see Chap. 5), the mechanical effects of the electrode within the heart and the electrical performance of the pacemaker lead.

- Mechanical effects of the lead
  - Particularly after an acute myocardial infarct a pacing lead within the right ventricle may provoke ventricular ectopic activity and ventricular arrhythmias. Removal or repositioning of the lead may occasionally be required.

  - Loss of capture, chest pain, new pericardial friction rub or pacing of the thoracic wall are early indicators of right ventricular free wall rupture. Ventricular perforation may result in hemopericardium and cardiac tamponade. After echocardiographic confirmation it might be necessary to drain the effusion with a percutaneous drain (see Chap. 9). On rare occasions a sternotomy for an open repair is necessary.
  - A lead dislodged into the coronary sinus should be suspected in case of a sudden rise in the pacing threshold, failure to capture or a right bundle brunch block. This imposes as a posteriorly directed catheter on a lateral chest X-ray. Repositioning of the lead under fluoroscopy is usually required.

- Electrical performance of the lead
  - If the pacing threshold exceeds 10 mA repositioning of the pacemaker electrode should be considered.
  - Sudden failure of the pacing system often has a very simple cause and can easily be rectified by checking the integrity of connections and battery status of the pacemaker.
  - If there is no capture in spite of documented pacing spikes the output should be increased in the first instance. In the long term repositioning or replacing the electrode should be considered.

- Meticulous care of the cannulation site and the pacing lead help avoid catheter related blood stream infections.
- Prolonged percutaneous pacing can cause burns to the skin.

Chapter 8
DC Cardioversion

Annette Vegas and Jane Heggie

Arrhythmias are common in post-operative and critically ill patients. The urgency of treatment will be dictated by the patient's vital signs and underlying pathology. Salient details about the patient's cardiac anatomy, hemodynamic stability, coagulation status, current medication as well as airway and ventilation status will need to be reviewed prior to the cardioversion. Correcting any precipitating causes and pharmacological treatment should be considered prior to electrical cardioversion. It is important to bear in mind that patients with atrial arrhythmias of unknown duration or approaching 36+h may need an echocardiographic study to rule out thrombus and might have to be commenced on anticoagulation.

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Indications

- New onset atrial arrhythmia with hemodynamic compromise
- Uncontrolled pre-existing atrial arrhythmia with hemodynamic compromise
- Ventricular tachycardia (VT) with hemodynamic compromise or ventricular fibrillation (VF) as part of the ACLS protocol. Wide complex QRS tachyarrhythmias may be supraventricular in origin with aberrant infranodal conduction, but they are best assumed to be ventricular until proven otherwise.
- Stable VT refractory to pharmacological interventions

Consent

If not sedated and/or intubated and ventilated the indication, procedure and potential complications associated with electrical cardioversion should be explained to the patient. Patients should be made aware of the following:

- Need for general anesthesia
- Induction of further arrhythmias
- Stroke
- Skin irritation

For obvious reasons consent is not necessary in emergency situations.

Preparation

- If applicable, the patient needs to be assessed for anesthetic purposes.
- If sedation or a general anesthetic (see Chap. 1) is required, a medical practitioner skilled in anesthetic procedures and airway management must be present.
- Rapid ventricular rates may respond to pharmacologic intervention or overdrive pacing while preparing for the cardioversion.

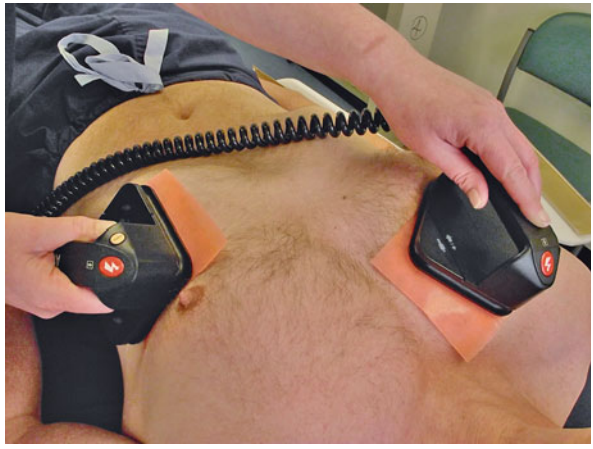

FIGURE 8.1 Gel pads in typical position before cardioversion

- Antecedent causes such as hypoxia or electrolyte imbalance should be corrected.
- If present, assess that temporary pacing system is working (see Chap. 7). Univentricular anatomy (e.g. cavopulmonary connections) where there is no access to the ventricle with a pacing wire requires particular caution.
- If anticoagulated, ensure there is evidence of adequate levels of anticoagulation.
- Gel pads that require the operator to hold the defibrillator paddles to the patient's chest (see Fig. 8.1) or self-adhesive electrodes (see Fig. 8.2), that also enable transcutaneous pacing (see Chap. 7), can be used. Electrodes have several advantages:
  - Lower risk of skin irritation or burns
  - Provision of ECG and pacing functionality
  - Decreased risk for the operator to sustain an electrical injury as no close proximity to the patient is necessary.
- The usual position for pads is antero-lateral in a supine patient. Patients who require a transesophageal echocardiogram in a left lateral position can have the pads placed in antero-posterior orientation (see Fig. 7.1).

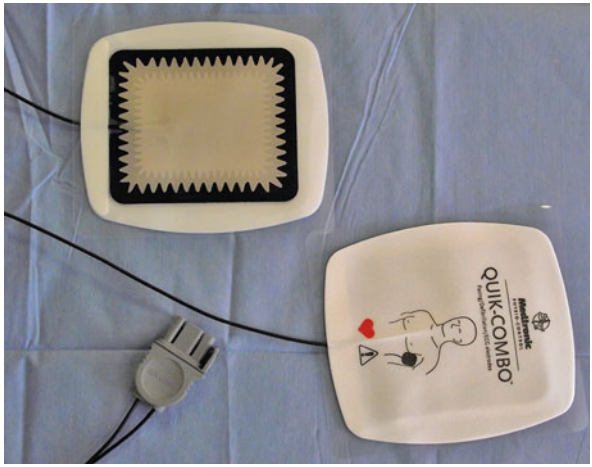

FIGURE 8.2 Cardioversion/defibrillation electrodes

- Resuscitation equipment and drugs (in particular for the treatment of bradyarrhythmias) need to be readily available.
- If the patient has been fitted with a temporary pacing system. It should be turned off and/or disconnected from the patient prior to cardioverting to prevent costly repair of the pacing box.

Procedure

- The operator is responsible for:
  - Making sure that the defibrillator is synchronized. Resuscitation for VF is the only occasion where a synchronous mode is not needed.
  - Making sure that none of the staff involved come to harm. All involved need to be aware when the defibrillator is being charged. By stating "all clear" the operator announces that the delivery of the shock in imminent. Before discharging the defibrillator the operator needs to visually inspect the patient's surroundings to make sure that no one has any physical contact with the patient or the bed.

- Start with 100 J of biphasic current and increase in 50 J increments to a maximum of 200 J; with monophasic defibrillators start at 200 J and incrementally increase to 360 J. If resuscitating for VF the maximum output energy should be chosen from the first shock on.
- If cardioversion is unsuccessful after three to four attempts the patient's electrolyte and acid base status should be re-evaluated.
- Permanent pacemakers will need interrogation and possibly re-programming post procedure.

Complications

- Bradycardia is the most common complication after cardioversion for atrial arrhythmias. If the patient is hemodynamically stable observation is all that is needed. Bradycardia that is symptomatic will need pacing (see Chap. 7) or drug therapy to increase the sinus rate or AV node conduction. Omitting drugs that block the AV node may be prudent.
- Whether to treat hypotension pharmacologically or with fluids will largely be dictated by the patient's underlying anatomy and pathology.
- The treatment of embolic events will depend on the end organ involved. Patients with new neurological symptoms will require a CT and re-evaluation of their coagulation status.
- Skin irritations are generally minor but can cause patients a degree of discomfort. Treatment with a burns cream and some analgesia normally help alleviate the symptoms.

Chapter 9
Pericardiocentesis

Adnan Sadiq and Michael Wall

Pericardiocentesis is a procedure in which a syringe and needle are passed through the chest wall and into the pericardial space in order to aspirate fluid. Pericardiocentesis has the potential to save someone's life, particularly in a situation of cardiovascular extremis resulting from tamponade. It also has the ability to kill, and therefore should not be undertaken lightly or without undue thought to the potential risks and harms associated with it. Indeed, blind pericardiocentesis (i.e. without ultrasound or CT guidance) carries a 10% mortality rate and a 50% morbidity rate.

Indications

- Emergency indication:
  - Life-threatening hemodynamic changes due to cardiac tamponade.
- Non-emergency indications:
  - Aspiration of pericardial fluid for diagnostic, palliative or prophylactic reasons.

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Diagnosis of Tamponade

Because the pericardium is stiff and non-compliant, fluid accumulating in the pericardial space can limit filling of the atria and/or ventricles, which can result in low cardiac output, hypotension and shock.

The classic teaching of cardiac tamponade consists of Beck's Triad – hypotension, jugular venous distension, and muffled heart sounds. However, not all patients will exhibit these findings. Hypotension is found in 70%, elevated jugular venous pulse in 40%, and muffled heart sounds in only 20%. A new triad has been described where hypotension or shock plus the presence of a pericardial effusion plus the absence of any other obvious cause of shock equals tamponade.

Transthoracic echocardiography (TTE) is suitable for diagnosing a pericardial collection in most situations. In overly obese patients or if dressings hinder access to the subcostal or parasternal regions of the chest wall transesophageal echocardiography (TEE) is useful.

On the echocardiogram a pericardial effusion appears as a black rim within the pericardium, surrounding the heart (see Fig. 9.1).

Not only large fluid collections cause tamponade. Regularly small, localized effusions compress a cardiac chamber enough to cause severe symptoms (see Fig. 9.2).

It is important to note that not all effusions cause tamponade. The echocardiographic features of tamponade (see Fig. 9.3) include

- collapse of the right atrium during systole
- collapse of the right ventricle during diastole
- dilated inferior vena cava (IVC) but empty right atrium and right ventricle
- respiratory variation of the mitral inflow velocities
- respiratory variation of the tricuspid inflow velocities

in combination with the clinical findings described above that confirm the diagnosis of tamponade.

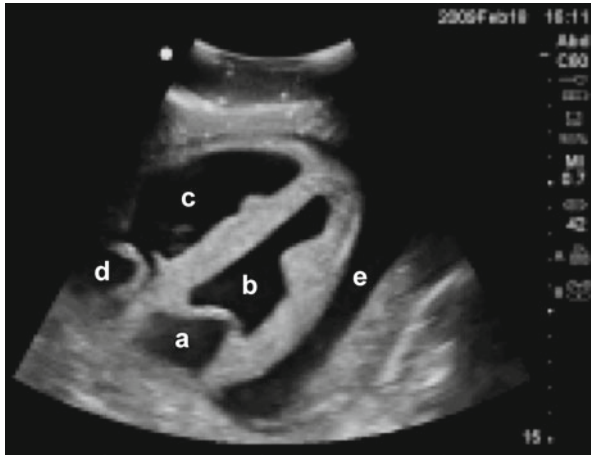

FIGURE 9.1 Subcostal four-chamber view showing a pericardial effusion and collapse of the right atrium, (**a**) left atrium, (**b**) left ventricle, (**c**) right ventricle, (**d**) right atrium, (**e**) pericardial effusion

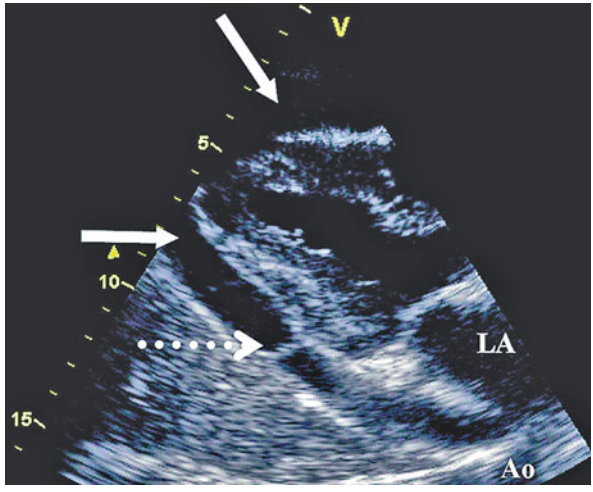

FIGURE 9.2 Parasternal long axis view. *Large white arrows* denonte pericardial effusion. *Dotted arrow* indicates fibrinous strand, distal to which is a light gray shadowing suggestive of clot with left atrial (LA) indentation

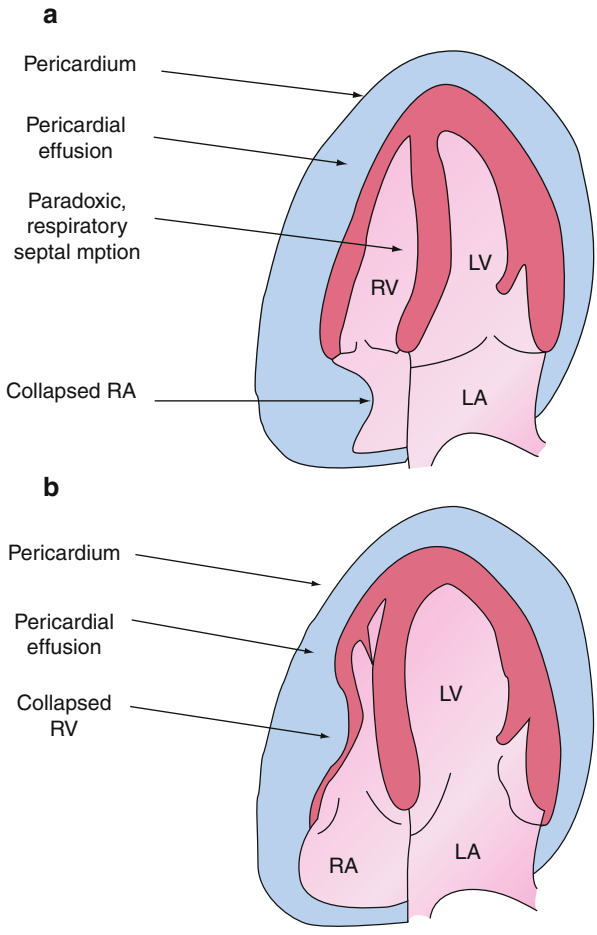

FIGURE 9.3 (**a**) Schematic 2D echo findings in systole with tamponade physiology. (**b**) Schematic 2D echo findings in diastole with tamponade physiology

Consent

If not sedated and/or ventilated or in an emergency situation with (pending) cardiac arrest the indication, procedure and potential complications should be explained to the

patient. They should be made aware of the following potential risks:

- Puncture of the myocardium or a coronary artery
- Pneumopericardium
- Arrhythmias induced by the needle
- Infection
- Puncture of surrounding structures.

Preparation

- Patients undergoing non-emergency pericardiocentesis should have any coagulopathy or platelet defect corrected.
- Pericardiocentesis should be carried out under aseptic conditions. The operator should wear gown, gloves, hat and mask for elective procedures. Even in emergency situations a pericardiocentesis should be carried out in as clean conditions as possible.
- Light sedation (see Chap. 1) and deep infiltration with a local anesthetic (usually lignocaine 2%) usually are adequate to make the procedure tolerable for conscious patients.
- The necessary instruments are laid out on a sterile procedure trolley (see Fig. 9.4).
- Emergency drugs and resuscitation equipment such as a defibrillator have to be immediately available.

Positioning and Identification of Site

- Patients will normally be in a supine position. If possible, the head end of the bed should be elevated to 30–40° to allow the effusion to pool inferiorly.
- Guided by ultrasound an entry site close to the pericardial space is selected. If no echocardiogram is available, the needle is introduced at the point where the left costal margin meets the xiphisternum (see Fig. 9.5).

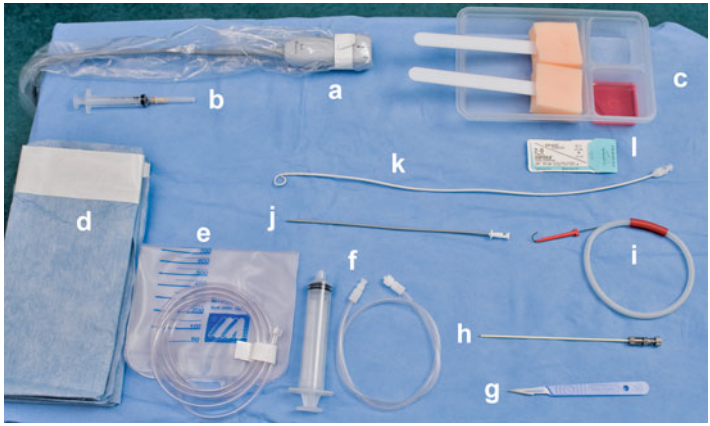

FIGURE 9.4 Procedure trolley for pericardiocentesis using ultrasound guidance: (**a**) ultrasound probe in sterile sleeve, (**b**) needle and syringe for local anesthetic, (**c**) tray with antiseptic skin prep and applicators, (**d**) sterile drapes, (**e**) drainage bag, (**f**) 30 mL syringe and extension for aspiration of pericardial fluid, (**g**) scalpel, (**h**) puncture needle with trocar, (**i**) guidewire, (**j**) dilator, (**k**) multi-orifice pigtail catheter, (**l**) suture

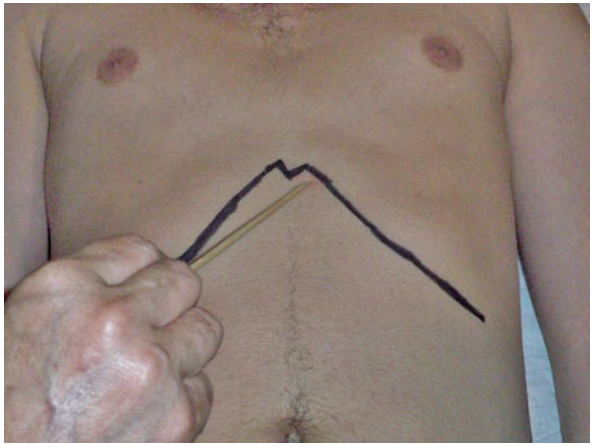

FIGURE 9.5 Point of entry just to the left of the xyphoid process

Procedure

Unless the patient's life is immediately in danger, pericardiocentesis should be performed by an experienced operator under ultrasound guidance in an area equipped for advanced hemodynamic monitoring and resuscitation. ECG guided drainage of pericardial effusions and collections is still performed occasionally.

- The skin is prepared with an anti-septic solution from the level of the mammillae to the umbilicus. Sterile drapes are applied, adequately exposing the subxiphoid area.
- If appropriate, the area around the entry point is infiltrated with local anesthetic.
- A small stab incision is made at the previously identified entry point.
- The needle is introduced at an angle of 15–20° to the abdominal wall and advanced under continuous aspiration toward the tip of the patients left shoulder.
  - Ultrasound guidance:
  - The needle is advanced after either the parasternal long axis view or the subcostal four-chamber view has been acquired. The position of the needle has to be visible at any time.
  - ECG guidance:
  - The pericardial needle is connected to an ECG lead. When the needle touches the epicardium or the myocardium an ST segment elevation will be noticeable on the ECG (see Fig. 9.6). At this point the needle is withdrawn until the ST segment normalizes.
- Once fluid is aspirated there are several ways to confirm that the needle is in the epicardial space:
  - If 1–2 mL of agitated saline or albumin are injected, spontaneous contrast, microbubbles or swirls of fluid will be seen on echo.
  - In case blood is aspirated, some of the gained fluid is put into a small pot. If the blood fails to clot, it is likely to be intrapericardial; if the blood clots, it is likely to be intracardiac or intravascular.

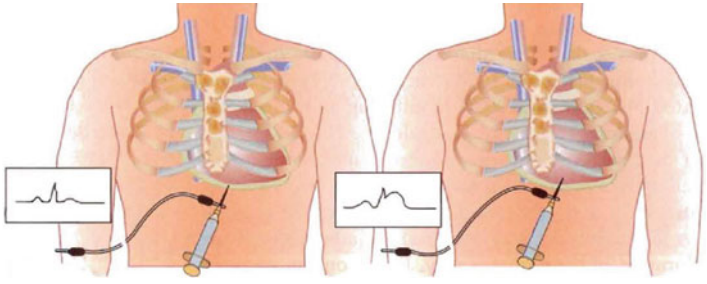

FIGURE 9.6 The needle is connected to an ECG monitor and is advanced pointing toward the left shoulder. An ST elevation is seen on the ECG as the needle touches the epicardium. The needle is withdrawn slightly until the ST elevation disappears

- Once the pericardial space has been confirmed to contain the needle tip, the syringe is detached and a wire is passed through the needle in Seldinger fashion. The needle is removed, the subcutaneous tissue and parietal pericardium are dilated with the dilator. The catheter is then placed over the wire.
- Once the catheter is in place, all pericardial fluid should be aspirated. Samples can be sent for biochemical, cytological, bacteriologic, and immunologic analysis.
- The catheter needs to be securely sutured into place and covered with a sterile dressing.
- Depending on the clinical situation the catheter is either connected to a sterile collection system for continuous drainage or closed off with a stopcock.
- After the procedure the patient needs close observation. Repeat echocardiograms should be considered to check for re-accumulation of fluid, particularly when the catheter has been closed. A chest X-ray is advisable to exclude a pneumothorax.

Complications

Complications rates for echocardiography-guided pericardiocentesis have been reported to be between 1.2% and 4.7%. The majority of complications are severe and require immediate surgical intervention.

- Hemothorax from
  - Laceration/puncture of heart
  - Laceration/puncture of coronary arteries or bypass grafts.
- Liver laceration
- Puncture of abdominal viscera
- The less severe complications include:
  - Arrhythmias are often caused by mechanical irritation through the catheter. Withdrawing it by several mm often solves the problem.
  - Pneumothorax (see Chap. 10)

Chapter 10
Intercostal Chest Drain Insertion

Sukumaran Nair and Florian Falter

The healthy parietal pleura secretes 100–150 mL of pleural fluid per day. The pleural space usually contains 30–50 mL of fluid and is free of air. This ensures the smooth movement of the parietal and visceral pleura during the respiratory cycle and prevents the lungs from collapsing by maintaining a negative pleural pressure. Generally excessive fluid or air need to be removed from the pleural space as they can severely impair respiratory mechanics. Apical intercostal chest drains (ICD) are ideal to drain air while basal ICDs are more effective in draining fluid from the pleural cavity.

Indications

- Pleural effusion
- Pneumothorax
- Hemothorax

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- Chylothorax
- Pyothorax
- Early empyema

Consent

If not sedated and/or intubated and ventilated the indication, procedure and potential complications associated with chest drain insertion should be explained to the patient. Serious complications are rare. However patients should be made aware of the following:

- Excess bleeding
- Infection
- Though local anesthesia is very effective, many awake patients describe the pressure from the operator's finger as quite painful.

Preparation

- Where appropriate any coagulopathy or platelet defect should be corrected.
- Chest drain insertion is a clean procedure, performed under aseptic conditions. The operator has to scrub and wear gloves, gown, mask and hat. Prophylactic antibiotic cover is not normally indicated.
- Generally deep infiltration with a local anesthetic (usually lignocaine 2%) is sufficient to make the procedure tolerable for conscious patients. This may be supplemented with some short-acting sedation in anxious individuals (see Chap. 1).
- Due to the positive pressure intubated and ventilated patients are at a higher risk of accidental lung injury. Any PEEP should be reduced as low as clinically tolerable during the procedure.
- Good exposure and visibility are key to avoiding any complications. It is advisable to use either a mobile theatre light or a headlamp.

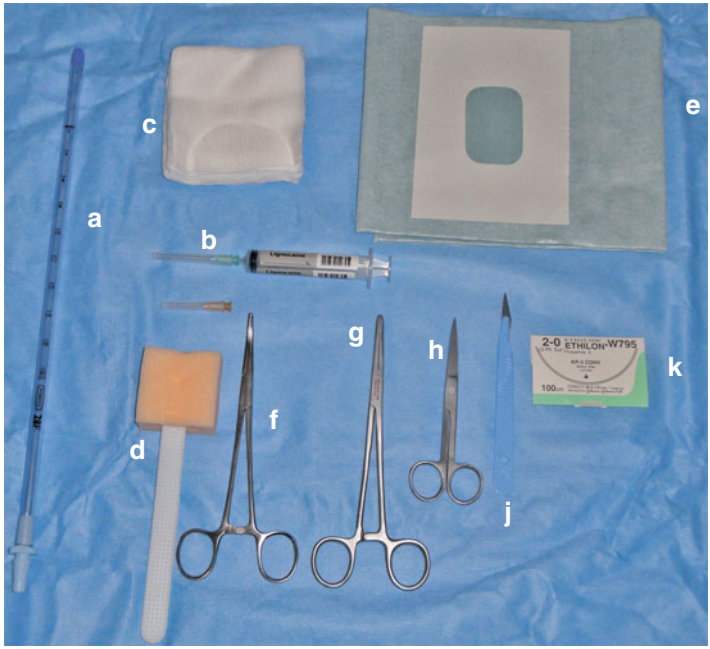

FIGURE 10.1 Set-up for chest drain insertion. a = 28F chest drain, b = syringe and hypodermic needles for local anesthetic, c = swabs, d = swab on stick for skin disinfection, e = sterile drape with hole, f = dissecting forceps, g = tubing clamp, h = scissors, i = knife for skin incision, k = suture for purse string

- The necessary instruments need to be laid out sterile on a procedure trolley (see Fig. 10.1).
- The drainage system with an underwater seal has to be prepared and tested before the procedure.

Positioning and Identification of Site

The patients will usually be in supine position, with the head end of the bed elevated by 30–40°. The operator is positioned so that the site of insertion is approximately at the level of their elbow or slightly above.

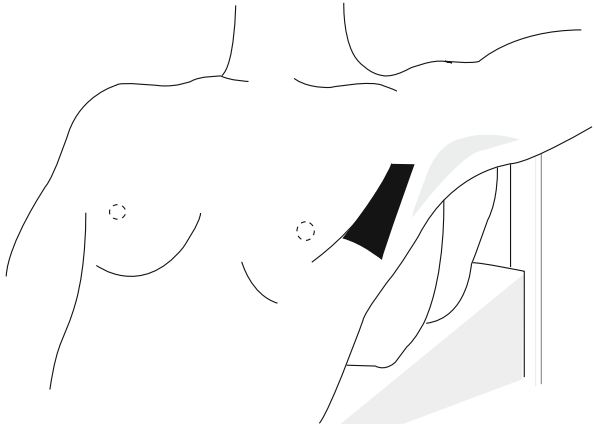

Figure 10.2 Patient positioning for access to the "safe triangle"

The drain is ideally inserted through the fourth or fifth intercostal space in the mid-axillary line, which corresponds to the "safe triangle". This relatively amuscular and avascular area is bordered anteriorly by the lateral margin of the pectoralis major, posteriorly by the anterior margin of the latissimus dorsi and the inferiorly by the origin of the serratus anterior (see Fig. 10.2).

In very unstable emergency patients chest drains may be inserted anteriorly through the second intercostal space in the mid-clavicular line. This is almost only ever done for a tension pneumothorax or in trauma victims where quick re-expansion of the collapsed lung is life-saving.

Procedure

The lateral chest wall is prepared with an antiseptic solution, extending from the roof of the axilla superiorly to the costal margin inferiorly and the mid-clavicular line anteriorly to the axillary fold posteriorly. Surgical drapes are applied to expose the "safe triangle". As a rule, chest drains with trocars are no longer used to decrease the risk of visceral injury.

The site of incision is identified over the fourth/fifth intercostal space in the mid-axillary line by counting down from the second intercostal space anteriorly. Once identified the site is infiltrated with 10–20 mL of local anesthetic in the following order:

- Line of incision
- Deeper superficial fascia
- Periosteum of the rib inferior to the intercostal space
- Superior margin of the rib to infiltrate the neurovascular bundle traversing the intercostal space
- Parietal pleura.

The parietal pleura is punctured at this stage to aspirate either air or fluid confirming the appropriateness of the site of insertion. Samples of the pleural aspirate for bacteriology, cytology, immunology or biochemistry should be taken at this point.

After giving the local anesthetic 3–5 min to act, the procedure progresses as follows:

- 2.5–3 cm horizontal incision in the fifth intercostal space in mid-axillary line
- Deepen incision to the subcutaneous fat layer
- Insert a purse string and a drain holding tie to the skin edges of the incision. The ends of these sutures are clipped and kept away. 2/0 Nylon or Ethilon sutures are typically used for the purse string, while a robust material like 1 silk is used for the drain holding tie.
- Using blunt dissection with a dissecting artery forceps, the external intercostal muscle layer is exposed. The fibers (directed obliquely forwards from above) are split parallel to their normal orientation.
- The parietal pleura is reached and can be felt with the index finger tip.
- After puncturing the parietal pleura with the tip of the artery forceps the index finger is then passed into the pleural space and swept around to make sure there are no adhesions between the lung and pleura.
- It is good practice to seal the wound with the index finger at the point of pleural puncture to avoid spillage of fluid on to the patient's bed.

- Using a curved long artery forceps the tip of the chest drain is pushed carefully and gently into the pleural space.
- Remove forceps when the tip of the drain has been advanced 5 cm into the pleural space.
- Direct the drain either towards the diaphragm or towards the neck of the patient depending on whether the intention is to drain fluid or air.
- The drain should be advanced at least 5 cm from the last side-hole to allow adequate build-up of negative pressure when suction is applied.
- Once secured in position with the previously inserted drain-holding suture, the drain is connected to the drainage system. Suction of –3 to –5 kPa enables effective drainage of both air and fluids and helps re-expansion of the collapsed lung.
- The wound is dressed with a sterile dressing.

A chest X-ray has to be done shortly after the drain insertion to

- check the position of the drain,
- ensure acceptable lung re-expansion and/or drainage of pleural effusion,
- exclude possible complications.

Common Complications

- Bleeding is most commonly caused by injury to an intercostal artery or vein. If the patient remains cardiovascularly stable and does not require any blood transfusion, conservative management is advised. The chest X-ray should be repeated after 4–6 h to rule out an expanding hemothorax. Should the patient become cardiovascularly unstable with the need for volume resuscitation or if there is evidence of an enlarging hemothorax the patient should undergo an exploratory thoracotomy. Identifying and ligating the bleeding vessel normally solves the problem.
- An unsterile surgical field or breach of asepsis during drain insertion can cause infection. Once an infection of the insertion site or the pleural space is suspected, the

drain should be removed and the patient treated with antibiotics after obtaining wound swabs for microbiological culture. If the patient still needs a chest drain at this point, a new one should be inserted as far away from the focus of infection as possible.

- Pain at the insertion site is mostly caused by irritation of the intercostal nerve. If pain proves to be refractory to increased does of conventional analgesia, it can be treated with intercostal blocks. Shoulder tip pain is usually due to the chest drain sucking on the diaphragm or the apical parietal pleura. Detaching the drain from suction will solve the problem for many patients. If this does not help, withdrawal of the chest drain by about 2 cm after confirming its position by X-ray usually relieves the pain.
- Migration of chest drains is not uncommon, particularly when they have been in place for a long time. Slipped out drains must not be pushed back into the chest, as this increases the risk of pleural space infection dramatically. A slipped out drain should always be removed and replaced with a new one, inserted through a separate incision.
- Surgical emphysema following chest drain insertion is usually due to a side hole remaining outside the rib cage and leaking air into the chest wall. A chest X-ray will confirm this. The chest drain should be removed after re-insertion of another drain through a separate incision. Occasionally, surgical emphysema is caused by air being sucked in at the insertion site. The incision site should be made airtight by inserting an extra suture in this case.
- Lung injury can also lead to surgical emphysema but will normally be accompanied by a concomitant air leak. Depending on the severity of the injury, the problem is treated either by taking the drain off suction or, in severe cases, by over-sewing the injured lung surface during a thoracotomy.
- Rarely, chest drain insertion can lead to injury of other thoracic and abdominal organs. Injuries to diaphragm, esophagus, liver, spleen or even the heart have been reported. These injuries require emergency surgery.

Chapter 11
Percutaneous Endoscopic Gastrostomy Tube Placement

Babak Sarani

Owing to the fact that it is easy and safe to perform the placement of percutaneous endoscopic gastrostomy (PEG) feeding tubes has become common in the ICU. It is used for patients who are unable to meet their nutritional requirements with oral intake and where passing a nasogastric tube is contra-indicated or where long-term enteral nutrition is anticipated. Neurological deficit with difficulties protecting the airway after stroke is the most common indication for placing a PEG.

Indications

- Impaired ability to swallow
- Inability to protect airway
- Altered level of consciousness
- Prolonged need for gastric decompression

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- Gastric fixation for recurrent gastric volvulus
- Head injury
- Facial burns/reconstructive surgery

Contraindications

- Inability to perform an upper endoscopy
  - Obstructing esophageal tumor
  - Esophageal stricture
- Ascites/peritoneal dialysis
- Peritonitis
- Patients with short life expectancy

Relative Contraindications

- Coagulopathy
- Portal hypertension/gastric varices
- Previous gastric resection
- Abdominal wall infection
- Morbid obesity

Consent

If not sedated and/or intubated and ventilated the indication, procedure and potential complications associated with PEG tube placement should be explained to the patient. Specifically, patients should be made aware of:

- A 1:1,000 risk of colonic injury requiring colon resection
- Excess bleeding
- Infection
- If the PEG tube is accidentally removed within 1 week of insertion, an emergency operation will be needed to replace the tube. This can be done either using a laparoscopic or open approach.

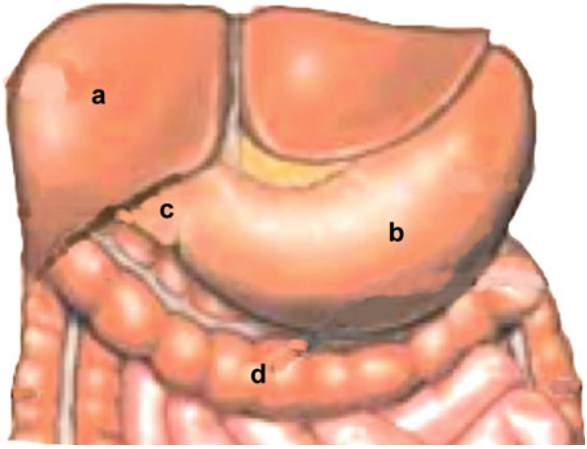

FIGURE 11.1 Normal anatomy of upper abdominal contents, (**a**) liver, (**b**) stomach, (**c**) duodenum, (**d**) transverse colon

Preparation

The stomach is situated in the mid epigastric region and extends to the left upper quadrant of the abdomen. The transverse colon is normally situated just inferior to the stomach (see Fig. 11.1), but can assume a position anterior to the stomach if it is distended. An appreciation of these relationships is critical in minimizing the risk for colon injury during PEG tube placement.

- An endoscopist and an operator are needed for this procedure.
- Any coagulopathy should be corrected as appropriate.
- Prophylactic antibiotic cover is not generally needed.
- If not sedated and intubated and ventilated the patient should be given conscious sedation (see Chapter 1) for the passage of the endoscope into the stomach. The site where the PEG tube will be placed should be infiltrated with local anesthetic, usually 20 mL of lignocaine 2%.
- Commercially available PEG insertion kits contain all necessary equipment except a drainage/collection bag and the endoscope (see Fig. 11.2).

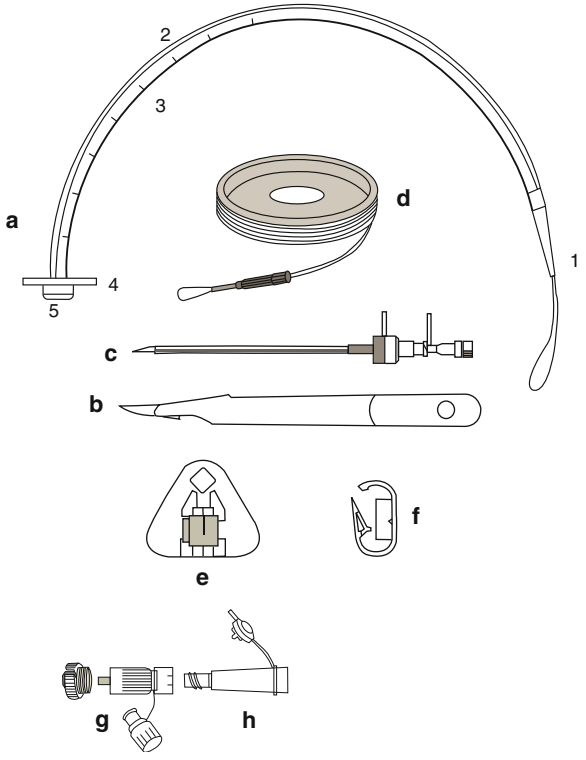

FIGURE 11.2 PEG insertion kit. (**a**) PEG tube, 1 = proximal cone with integrated fixation loop, 2 = radio-opaque strip, 3 = measuring marks, 4 = silicone retention plate, 5 = rounded distal opening, (**b**) No 11 blade, (**c**) puncture cannula, (**d**) reel of thread with double thread and introducer, (**e**) external silicon fixation plate, (**f**) tube clamp, (**g**) Luer lock connector, (**h**) funnel adapter (Reproduced with kind permission from Fresenius Kabi)

Position

The patient is in a supine position. A bite block should be used to minimize the chances of inadvertent damage to the endoscope.

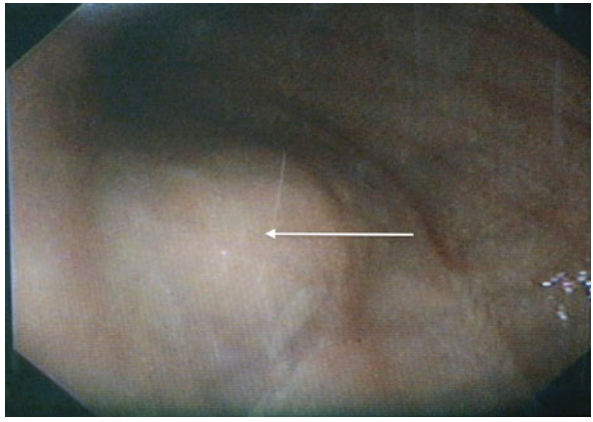

FIGURE 11.3 Endoscopic view of the stomach wall at the point of maximum indentation (*arrow*)

Procedure

- The abdomen is cleaned and draped from the umbilicus to the xyphoid. Although aseptic technique is not mandatory, the operator should wear a gown, gloves, mask and hat for protection from body fluids.
- The endoscope is advanced into the stomach via the mouth.
- If in place, the path of a nasogastric (NG) tube can be followed. However, the presence of a NG tube can make advancing the endoscope difficult in small patients.
- A complete endoscopic evaluation of the stomach and esophagus should be performed prior to PEG tube placement.
- The stomach is insufflated until all ruggae disappear. Distending the stomach this way ensures that it is as closely apposed to the abdominal wall as possible.
- The operator pushes with one finger just to the left of midline and approximately 2–3 finger width below the costal margin into the abdominal wall, until the endoscopist is able to identify the point of maximal indentation in the stomach (see Fig. 11.3). It is important that the pressure

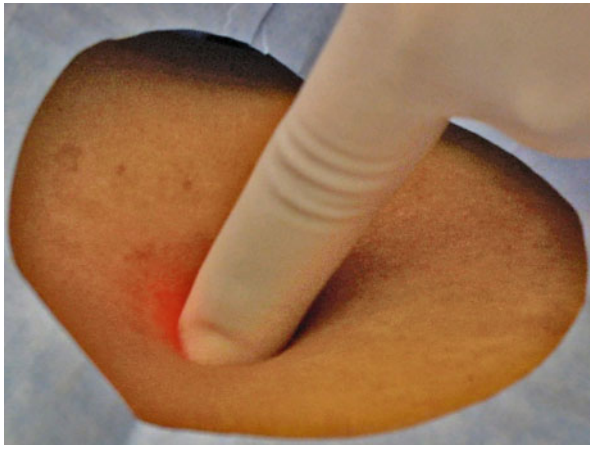

FIGURE 11.4 Good transillumination at the point of maximum indentation as seen by the operator

exercised by the operator is discrete. Good indentation without exercising much pressure suggests that the stomach is compressed directly, rather than the colon, which in turn compresses the stomach.

- The endoscope is advanced to the region of maximal indentation and its light intensity turned up as high as possible to assess the ability to transilluminate (see Fig. 11.4). Failure to either endoscopically identify a point of maximal indentation or to transilluminate suggests intervening viscera or inadequate gastric apposition against the abdominal wall.
- The endoscopist advances a snare via the working channel of the endoscope and positions it at the point where the PEG tube will be placed
- The operator positions a syringe filled with saline onto the large bore needle/catheter. The assembly is passed into the stomach under continuous aspiration at the previously identified point. Air should only be aspirated once the endoscopist sees the needle in the stomach. Earlier aspiration of air suggests a colonic puncture.

- The needle is removed leaving the catheter in the stomach.
- A guidewire is placed into the stomach through the catheter. Once visible through the endoscope, the wire is grasped with the snare.
- The guidewire, snare, and endoscope are withdrawn as a unit. The operator holds on to their end of the guidewire.
- The endoscopist secures the PEG tube to the guidewire by:
  - Passing the guidewire through the pre-positioned loop wire on the PEG tube (see Fig. 11.5a)
  - Passing the PEG tube bumper through the loop in the guidewire (see Fig. 11.5b)
- An incision big enough to accommodate the PEG tube is made in the abdominal wall. As the operator pulls back the guidewire, PEG and endoscope follow until the PEG exits the stomach. The bumper remains in the stomach and holds the PEG tube in place (see Fig. 11.6).
- In most patients the 2–4 cm mark of the PEG tube will be at skin level. Before withdrawing the endoscope the position of the bumper is checked. It should be placed against the gastric mucosa in such a way that it is tight but can still rotate.
- The PEG tube is secured in place by sliding the external disk over the tube. It should be sufficiently tightened to make a small indentation on the skin. At the operator's discretion the disc may be sutured to the skin.
- The PEG tube is cut to size, connected to a bag and initially left on free drainage.
- Feeding via the PEG tube can commence within 2–4 h following insertion.

Common Complications

- A pneumoperitoneum is an expected finding on CT scanning for several days following the procedure. It may also be noted in up to 33% of cases using plain X-ray techniques.

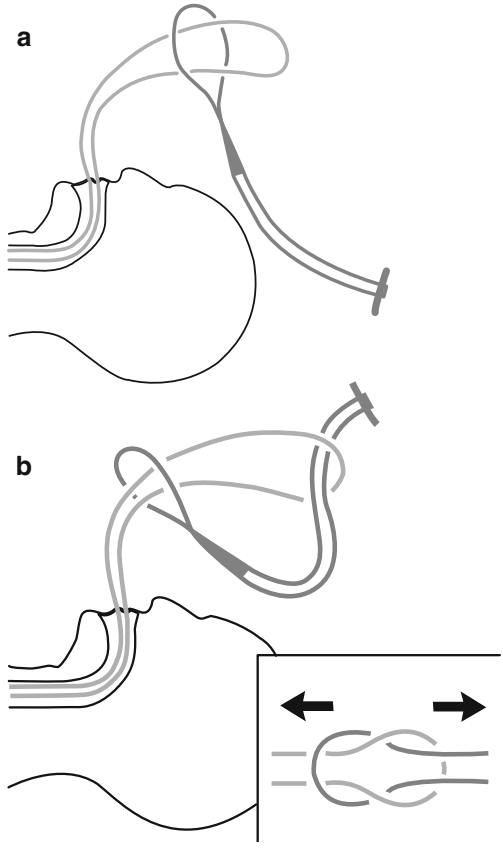

Figure 11.5 (**a**) Passing the guidewire through the pre-positioned loop wire on the PEG tube. (**b**) Passing the PEG tube bumper through the loop in the guidewire (Images reproduced with kind permission from Fresenius Kabi)

Multiple attempts at accessing the stomach with the needle and a prolonged procedure time increase the incidence.

- PEG tube dislodgment should be considered when a pneumoperitoneum is coupled with abdominal pain or signs of sepsis or if it is noted more than 1 week after PEG tube insertion. Adequate tube positioning can be checked using

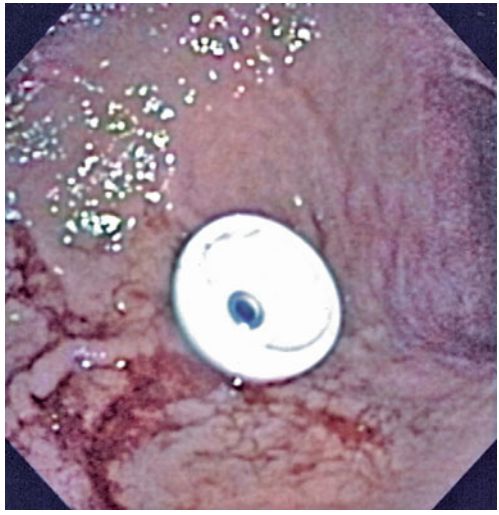

FIGURE 11.6 Bumper in final position against the stomach wall

CT scanning or by injecting water-soluble contrast via the PEG tube and obtaining a flat-plate plain X-ray of the abdomen.

- Tube dislodgement is a concern if the PEG tube is removed <1 week from the time of insertion because a fistulous tract may not have developed. This results in an uncontrolled gastric perforation. A surgeon should be consulted to determine the need for operative replacement of the tube.
- PEG tube dislodgement more than 1 week after placement rarely results in an uncontrolled gastric leak but the gastrocutaneous tract can close very quickly. A tube should be placed through the tract as early as possible to maintain it. A Foley catheter is mostly used for this purpose as the balloon can be inflated to anchor it in the stomach. Once it has been sited, correct positioning of the Foley catheter has to be confirmed using water-soluble contrast, as discussed above.
- Wound infection following PEG placement is very rare. Mucoid discharge may be noted at the insertion site. This frequently is gastric mucus leaking around the tube and not

an active infection. Keeping the initial skin incision as small as possible and tightening the tube at the skin level may alleviate the problem. Incision and drainage may become necessary if a subcutaneous fluid collection develops.

- Colonic injury occurs in 1:1,000 cases. The incidence can be minimized by:
  - ensuring adequate indentation of the stomach with palpation of the overlying skin,
  - transillumination,
  - loss of suction on the syringe with visualization of the introducer needle in the stomach.
- Accessing the colon with the introducer needle is innocuous but placement of the PEG tube in the colon necessitates either colon resection or repair. Symptoms such as diarrhea resembling enteral feed, abdominal pain, feculent drainage via the PEG tube or signs of sepsis should give rise to the suspicion of colonic PEG tube placement. A CT scan, colonoscopy, or a plain X-ray with water-soluble contrast will confirm the tube position.
- Hemorrhage following PEG tube placement is rare and is mostly caused by bleeding from the gastric mucosa. It generally manifests as bleeding from the PEG tube. It is most commonly seen in patients with pre-existing coagulopathy or gastric varices but may be also due to gastric mucosal necrosis when too much pressure is applied between the stomach and PEG tube bumper. This is best addressed and treated via endoscopy.
- Distal migration of a gastric tube can occlude the pylorus and result in a gastric outlet obstruction. Due to the high profile of the balloon and difficulty with fixing it at skin level this is more common when a Foley catheter is used in place of a PEG feeding tube. Positioning can be easily assessed using the distance markers on the tube.

Chapter 12
Gastroesophageal Balloon Tube Tamponade

Ali Al-Khafaji, Su Min Cho, and Rebecca A. Gooch

Balloon tube tamponade is a life saving intervention in patients with active variceal bleeding, especially if emergency endoscopic intervention is unavailable or not possible. Esophageal varices are usually fed from abdominal vessels such as the coronary vein and short gastric vein that enter the chest through the diaphragm around the gastroesophageal (GE) junction. Increased portal pressure can cause dilatation of the coronary vein, which often leads to the formation of thin-walled, fragile varices below the esophageal and stomach mucosa. Applying pressures on the GE junction will tamponade the GE junction vessels and effectively stop bleeding. In other words, it is the pressure on the "feeding vessels" rather than pressure on the actual varices that stops the bleeding.

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Indications

- Active hemorrhage from esophageal or gastric varices
- Failure to control variceal bleeding by endoscopic means
- Patients too unstable to undergo endoscopic, interventional or surgical treatment
- Mallory Weiss tear (rarely)

Contraindications

- Presence of esophageal stricture
- Recent esophageal surgery

Consent

This is an emergency procedure, performed on often very distressed patients, for which consent is not normally taken. However, the procedure and its implications should briefly be explained to the patient, if appropriate.

Types of Tubes

The currently used tubes all follow the same design (see Fig. 12.1), but vary in the number of available channels.

- Sengstaken-Blakemore three-lumen tube with esophageal and gastric balloons, and gastric aspirate channel. Usually there is no need to insert a nasogastric tube for esophageal aspiration
- Minnesota four-lumen tube, with esophageal and gastric balloons, and esophageal and gastric aspiration channels
- Linton and Nachlas tube, with a large gastric balloon, and gastric and esophageal aspiration channels

The Sengstaken-Blakemore tube and the Minnesota tube are most commonly used.

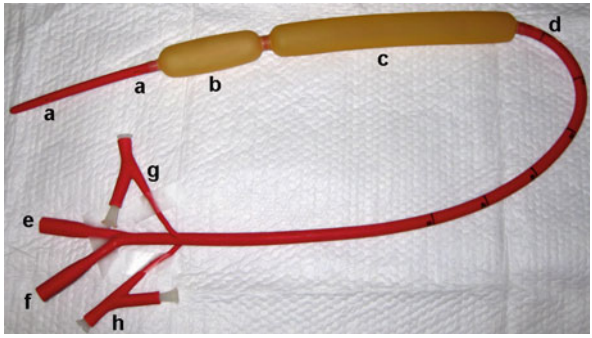

FIGURE 12.1 Minnesota tube, (**a**) gastric aspiration holes, (**b**) gastric balloon, (**c**) esophageal balloon, (**d**) esophageal aspiration holes, (**e**) gastric aspiration port, (**f**) esophageal aspiration port, (**g**) gastric balloon inflation port, (**h**) esophageal balloon inflation port

Preparation

- It is advisable to intubate and ventilate patients in order to protect the airway (see Chap. 2).
- Prior to insertion the gastric and esophageal balloons should be inflated with air to ensure that they are intact.
- The patency of the aspiration ports should be checked.
- The tube has to be adequately lubricated with lignocaine or KY jelly.

Patient Positioning

The procedure is easiest to perform if the patient is positioned either in a semi-erect or left lateral decubitus position with head tilted down if possible.

Procedure

- The lubricated tube is passed either transnasally or transorally to the level of the aspiration / inflation ports or at least to 45 cm. There should be no resistance to the tube passing.

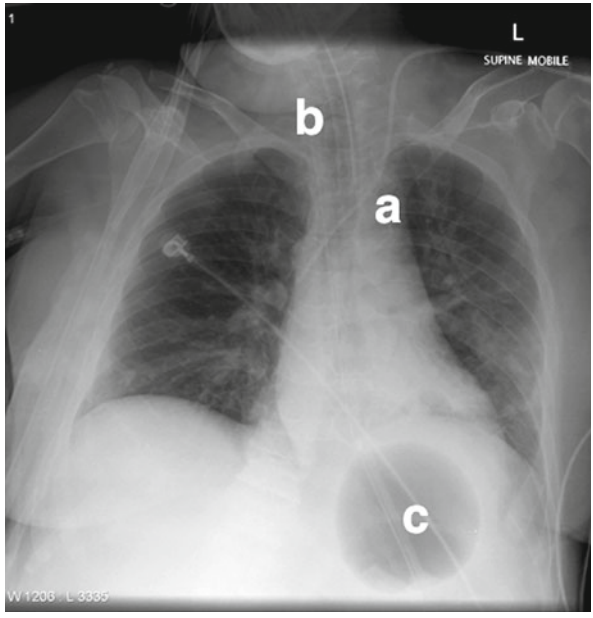

Figure 12.2 Chest X ray after gastroesophageal balloon tube placement, (**a**) central venous catheter, (**b**) endotracheal tube, (**c**) gastroesophageal tube, balloon inflated in the stomach

- Gastric placement of the tube can initially be confirmed by hearing a gush of air over the epigastrium after insufflating at least 20 mL of air via the gastric aspiration port. Frequently, blood is aspirated via the gastric aspiration port.
- The gastric balloon is inflated with 50–100 mL of air before obtaining a ½ chest, ½ abdomen X ray to ensure that the balloon is below the diaphragm (see Fig. 12.2).
- If the patient is hemodynamically critically unstable the above step can be skipped. Instead 200 mL of air is insufflated in the gastric balloon and the tube is pulled back gently until a resistance is felt. This confirms that the balloon is now abutted against the GE junction.
- After the correct position is confirmed the desired volume of air, usually 300–450 mL is injected to the gastric balloon.

If bleeding continues despite this inflating the esophageal balloon should be considered:

- A Lopez stopcock is put on the esophageal balloon port.
- A dry monitoring line, such as CVP measurement tubing, or a manometer are placed on the end of the Lopez stopcock that is open to air.
- The esophageal balloon is slowly inflated to a pressure of 25–40 mmHg.
- The pressure needs to be monitored continuously.
- To avoid complications such as esophageal necrosis, it is recommend deflating the esophageal balloon every 2 h for 10–15 min before re-inflating it.
- Gastric and esophageal suction ports should be placed on low intermittent suction.
- The tube is secured by pulling it up with 2–3 lb of tension to ensure that the balloon is abutting the GE junction. The traction can be achieved by securing the tube to a helmet mounted constant traction spring or by using a pulley system.
- The following parameters should be documented after tube placement:
  - Insertion depth measured from lips or nare
  - Amount of air used to inflate the gastric balloon
  - If the esophageal balloon is inflated, how much air has been used and which pressure is achieved with that
  - Duration of balloon inflation

Serial chest X-rays should be preformed while the tube is in place to ensure continued proper placement and to rule out tube migration.

Removal of the GE Balloon Tube

If the esophageal balloon was inflated, it should be deflated first. Twenty-four hours later, with no rebleeding, the gastric balloon can be deflated. Again, if no rebleeding occurs, the tube is left in place for an additional 24 h, with both balloons down, after which it is removed.

Complications

- The incidence of pulmonary aspiration can be decreased with endotracheal intubation and low intermittent suctioning of the esophageal port
- Esophageal erosion or rupture may be avoided by closely monitoring the inflation pressure of the esophageal balloon
- Respiratory obstruction can be alleviated by relieving some of the balloon pressure, thereby decreasing the pressure on the trachea
- Thoracic duct lymph obstruction may also be relieved by decreasing the balloon pressure
- Balloon migration has to be corrected as soon as it has been detected by chest X ray
- Chest pain or discomfort might require some analgesia in non-sedated patients
- Some complications will require intervention by a specialist:
  - Tracheoesophageal fistula formation
  - Jejunal rupture
  - Nasopharyngeal bleeding

Chapter 13
Suprapubic Catheterization

Ben E. Hughes and Oliver Wiseman

The empty bladder lies behind the pubic symphysis in the pelvis with folds of peritoneum pulled anteriorly between it and the anterior abdominal wall. As the bladder fills with urine it rises from the pelvis within the extra-peritoneal fat. When excessively distended it can reach to the level of the umbilicus. While filling, the bladder reflects the peritoneum away from its anterior surface so that, in theory, no peritoneum should lie between it and the anterior abdominal wall. Thus, a distended bladder can be relatively safely punctured superior to the pubic symphysis.

Indications

The placement of a suprapubic catheter (SPC) is indicated to relieve urinary retention when an attempt at urethral catheterization has been unsuccessful. It is frequently used in the following conditions:

- Urethral injuries
- Urethral obstruction

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- Benign prostatic hypertrophy
- Prostate cancer

SPC is not the appropriate option under the following circumstances:

- Bladder not easily palpable or can't be localized using ultrasound
- Unexplained hematuria or known carcinoma of the bladder
- The presence of a subcutaneous vascular graft in the suprapubic region (e.g. a femoro-femoral crossover graft)
- Previous lower abdominal surgery
- Pelvic fractures
- In patients who are fully anti-coagulated

Care should be taken in patients with a spinal cord injury above the level of T6 as they may be at risk of developing autonomic dysreflexia.

Consent

If a patient is awake and able to consent they should be informed of the following risks:

- Injury to abdominal organs
- Excess bleeding
- Infection
- Discomfort or irritation

Preparation

- It is now widely recommended that ultrasound is used to guide SPC insertion in order to identify any interposing bowel loops along the planned catheter track.
- Use incontinence bed pads underneath and to each side of the patient to absorb any spillage of urine.
- Antibiotic cover is recommended.

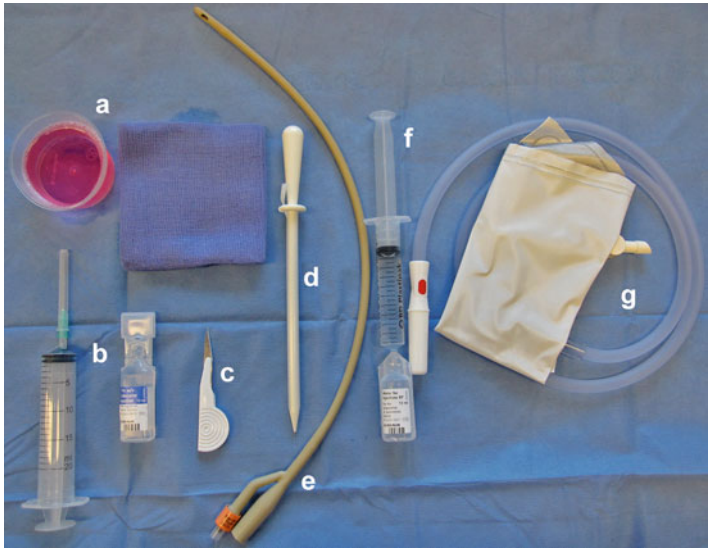

FIGURE 13.1 Procedure kit for SPC insertion, (**a**) skin prep and swabs, (**b**) 20 mL syringe and local anesthetic, (**c**) scalpel, (**d**) metal-tipped trocar and outer sheath, (**e**) silicone catheter (usually 14 or 16 Fr), (**f**) 10 mL syringe and water for injection to inflate balloon, (**g**) reservoir bag

- Deep infiltration with a local anesthetic (e.g. lignocaine 2%) is usually sufficient to make the procedure tolerable for awake patients. If necessary this may be supplemented with sedation and / or analgesia in some patients (see Chapt. 1).
- The procedure kit and any other necessary equipment need to be laid out on a sterile procedure trolley (see Fig. 13.1).
- SPC insertion is a clean procedure although surgical gowns, hat and mask are not necessary. The operator should wear sterile gloves and an apron for their own protection.

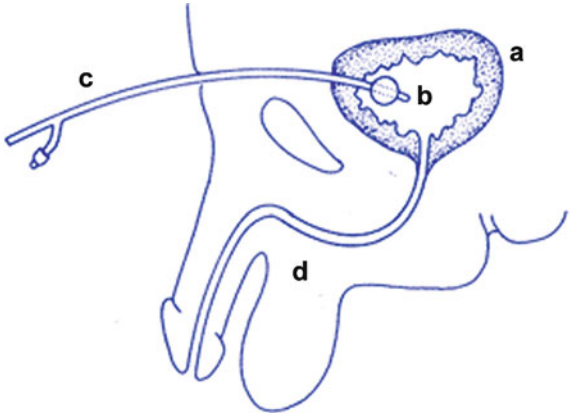

Figure 13.2 Insertion site for the suprapubic catheter, (**a**) bladder, (**b**) inflated balloon in the bladder, (**c**) urinary catheter, (**d**) urethra (Reproduced with kind permission from Femcare-Nikomed)

Positioning and Identification of Site

Patients will be supine, with the arms either by the side or folded across their chest. The ideal point of SPC insertion is in the midline, 1 finger's breadth (2 cm) above the pubic symphysis (see Fig. 13.2).

Procedure

- The anterior abdominal wall is prepared with aseptic solution from the pubic symphysis up to the umbilicus and draped.
- The operator has to ensure that an appropriately sized catheter that will slide easily through the introducing sheath, packaged around the trocar, is available.
- The catheter should be attached to the drainage bag to stop urine from spilling.
- Local anesthetic is applied generously by inserting the needle at 90° to the skin, infiltrating fat, rectus muscle and sheath all the way down to the bladder. Eventually urine will be aspirated. In obese patients a normal 21 G hypodermic

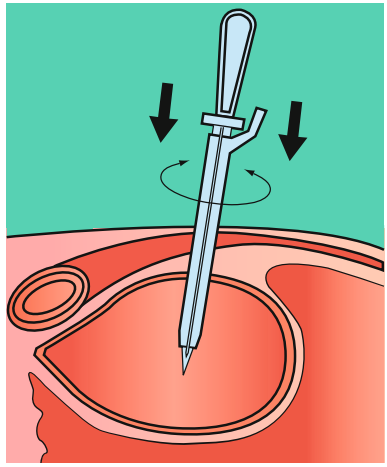

FIGURE 13.3 Insertion of trocar and introducer with a slight twisting motion (*arrows* indicate direction of movement of trocar into bladder) (Reproduced with kind permission from Femcare-Nikomed)

needle may not be long enough. A spinal needle should be used in that case to infiltrate the surgical area.

- Noting the depth at which urine can be aspirated helps to determine how far the trocar will have to be advanced to access the bladder.
- To facilitate introduction of the trocar, a skin incision <1 cm is made. Ideally the incision reaches down through the rectus sheath, but not through the bladder wall.
- It is helpful if the operator places their index finger on the shaft of the trocar at the level the bladder had previously been identified at. Thus upon insertion, when the tip of the finger touches the skin of the abdomen the trocar should be close to if not already through the bladder wall. Using the index finger as a guide helps preventing injury to the posterior bladder wall by the trocar.
- Trocar and sheath are inserted together at a 90° angle to the abdominal wall. Using a slight twisting motion allows smooth, controlled entry and minimal trauma on insertion (see Fig. 13.3). The sheath avoids separation during insertion due to the locking mechanism incorporated in the

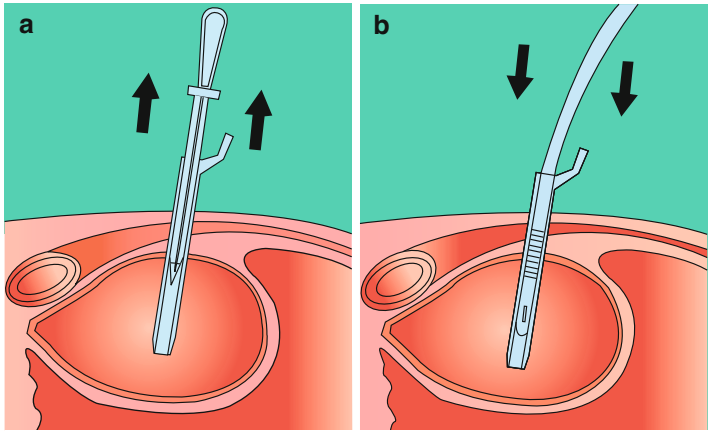

FIGURE 13.4 (**a**) Removal of trocar while leaving the sheath in place (*arrows* indicate direction of movement of trocar out of sheath); (**b**) Insertion of catheter through the sheath (*arrows* indicate direction of movement of catheter through sheath) (Reproduced with kind permission from Femcare-Nikomed)

handle. A small amount of urine will be seen rising along the trocar groove once the bladder has been entered – only proceed if this occurs.

- When the trocar is removed there will be a gush of urine. The Foley catheter should be inserted immediately through the sheath (see Fig. 13.4 a, b).
- The balloon at the catheter tip is inflated with a pre-prepared syringe containing 10 mL of sterile water (see Fig. 13.5).
- The sheath is withdrawn and removed from the catheter using the teardown strip (see Fig. 13.6).
- There is no need for external fixation with sutures
- After the procedure patients should be observed for signs of sepsis and inadvertent bowel injury.

There is a new seldinger technique for SPC insertion designed by Mediplus UK. The procedure is as described above but once the infiltrating needle is in the bladder a guidewire is passed through the needle into the bladder. The needle is

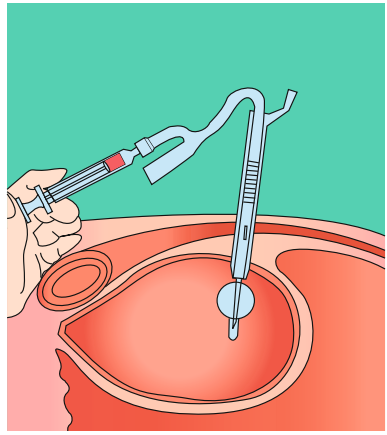

FIGURE 13.5 Inflating the balloon at the catheter tip (Reproduced with kind permission from Femcare-Nikomed)

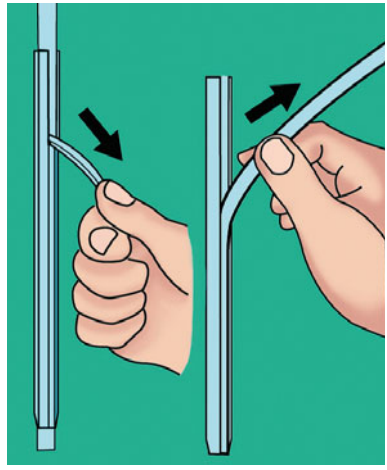

FIGURE 13.6 Withdrawing and removing the sheath (Reproduced with kind permission from Femcare-Nikomed)

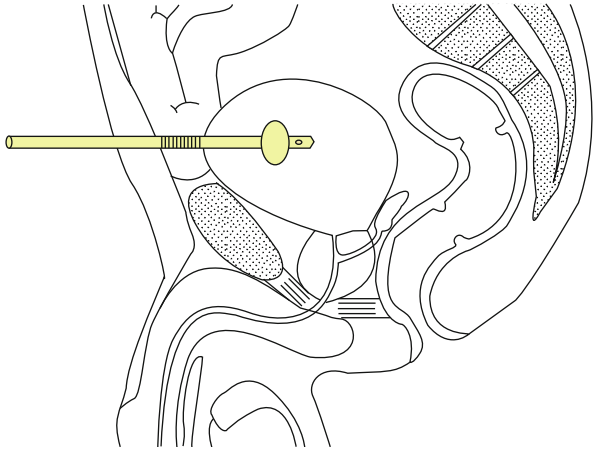

FIGURE 13.7 Accidental traversing of a bowel loop after suprapubic catheterization (Figure adapted from Ahmed et al. BMC Urol 2004;4:16, with kind permission from Biomed Central)

then withdrawn and the trocar is inserted over the guidewire.

Complications

- Some blood-staining of the urine is inevitable after the procedure.
- Hemorrhage from around the SPC insertion site or any significant hematuria is rare. In most cases gentle traction on the catheter will pull the balloon against the mucosal surface of the bladder and thus abdominal wall, helping to tamponade any bleeding. However, traction should not be maintained for longer than 30 min to avoid necrosis of the bladder mucosa.
- Bowel perforation (see Fig. 13.7) is a serious complication that often requires surgical intervention.

Chapter 14
Acute Compartment Syndrome

Lee van Rensburg

A compartment syndrome is characterized by increasing pressure in any fixed volume space within the body. This will lead to decreasing blood flow into the compartment with reduced tissue perfusion and subsequent tissue ischaemia. The term compartment syndrome is most commonly associated with the musculoskeletal system. It is worth bearing in mind that it is obviously possible for the same mechanism to occur in other closed body cavities, most noticeably as abdominal compartment syndrome (see Chap. 15).

Despite the fact that it is a mostly clinical diagnosis, it should be confirmed by measuring the pressure within the muscle compartments.

Indications

Two-thirds of acute compartment syndromes (ACS) are associated with a fracture. It is important to remember it may also follow significant soft tissue injury. ACS in the absence of trauma can be caused by

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- Circumferential burns
- Reperfusion injury following revascularization of ischemic limbs
- Calf or gluteal compartment syndrome following prolonged periods in lithotomy position, e.g. after urological or general surgical procedures.
- Compartment syndrome following pressure injection injuries, not only industrial but contrast agent injection under pressure for radiological procedures.

It is important to have a high index of suspicion. Several pitfalls and misconceptions exist and are important to note:

- Most clinicians are alert to the risk of ACS developing in patients with multiple trauma after a high-energy impact. However, low-energy, minimally displaced transverse fractures of the tibia are at the same risk of developing a compartment syndrome as high-energy, comminuted fractures.
- It is possible to get an ACS in any closed osseofascial compartment, although it is most common in the tibia and the forearm.
- It is possible to get an ACS in an open fracture.
- Physical examination alone cannot exclude an ACS. This is particularly important for tibia fractures. Even if the calf feels soft, a compartment syndrome might be present. It is not possible to feel the deep posterior compartment of the lower leg.
- Pulses are nearly always present, if absent an arterial injury has to be considered.

The cardinal clinical features are

- Increasing pain
- Pain out of proportion to what should be expected
- Pain on passive stretch of the muscles involved
- Paleness of skin
- Paresthesia indicates nerve ischemia and is a late sign
- Once paralysis is present irreversible nerve damage is likely to have occurred.

The nursing staff often discovers an evolving compartment syndrome in an awake and alert patient. Patients unable to

appreciate or verbalize the degree of pain they are in – such as patients with head injuries, those intubated and ventilated or with limb and spinal injuries – need active monitoring and consideration to exclude a compartment syndrome.

Pathophysiology

Tissue perfusion and oxygenation are dependent on inflow pressure, tissue pressure and outflow pressure. Ischaemia results from tissue pressure exceeding capillary pressure.

Different thresholds to initiate treatment have been suggested:

- Most universally accepted is a pressure of 30 mmHg within a compartment
- Increasingly a difference <30 mmHg between diastolic blood pressure (DBP) and intracompartmental pressure (CP) is being advocated (Delta p = DBP – CP)

It is important not to base the decision to perform a fasciotomy on only one single reading, but on the trend of repeated readings. Continuous pressure monitoring might be prudent in patients where clinical examination and communication is not possible.

Consent

No specific consent is necessary to measure the compartment pressure. Awake and alert patients should be informed about the procedure and the potential next steps.

Preparation

- No specific preparation is necessary
- The skin around the area where the needle will be inserted has to be cleaned and disinfected.

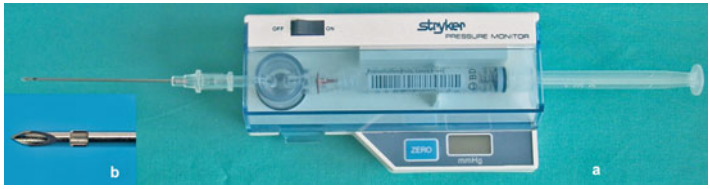

FIGURE 14.1 (**a**) Intra-compartmental pressure monitor, (**b**) needle with side port for compartment pressure monitoring

- The procedure has to be performed under sterile conditions.
- Depending on the equipment used, it might be necessary to calibrate the pressure monitor.
- Several commercially available compartment pressure monitors are available (see Fig. 14.1)
- For continuous monitoring a standard ICU pressure transducer system attached to the patient monitor can be used. It is important to use a side ported needle (see Fig. 14.1b) or slit catheter. Standard 18 G needles have been shown to over-read the compartment pressure.
- It is important to take readings in all the osseofascial compartments of the area of concern.

Procedure

- Continuous pressure reading:
  - Two slits are placed at the tip of a standard 18 to 20 Gauge, 15 cm central venous catheter.
  - After making a small stab incision in the skin with a scalpel, the catheter is inserted into the compartment to be measured.
  - A fluid filled extension line from the transducer is attached to the catheter. The transducer has to be zeroed at the level of the compartment.

  - It is important not to place the catheter into the fracture site. However, it is advisable to measure pressures within 5 cm of the fracture site.
  - After all the relevant compartments have been assessed, the catheter is placed in the compartment with the highest pressure and left there for continuous monitoring.
- Serial single measurements are taken under sterile conditions with most commercially available devices.

Complications

- The benefits of measuring compartment pressure in case of a suspected ACS by far outweigh the potential risks associated with this intervention.
- Complications are very rare.

Chapter 15
Abdominal Compartment Syndrome

Daniel D. Yeh and Stefan G. Simon

The Abdominal Compartment Syndrome (ACS) follows the same pathophysiological principles as other compartment syndromes: increased pressure in a confined space compromises lymphatic and vascular flow leading to hypoperfusion. Intraabdominal hypertension (IAH) is defined as sustained intraabdominal pressure (IAP) ≥12 mmHg and is divided into four stages:

- Grade 1, IAP = 12–15 mmHg
- Grade 2, IAP = 16–20 mmHg
- Grade 3, IAP = 21–25 mmHg
- Grade 4, IAP >25 mmHg

The term ACS refers to a clinical constellation resulting from increased IAP. The signs commonly include: oliguria, decreased pulmonary compliance and metabolic acidosis. Once fully developed, ACS carries a mortality of 40–100%.

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To enable assessment of the abdominal end-organ perfusion the concept of abdominal perfusion pressure (APP) has been introduced recently, APP = MAP–IAP (MAP = mean arterial pressure).

Measuring IAP is a relatively simple, risk-free procedure.

Indications

Patient characteristics associated with an increased risk of developing ACS are:

- >3.5 L positive fluid balance/24 h
- Massive transfusion (>10 u PRBC/24 h)
- Major trauma/burns
- Intra-abdominal infections
- Acute pancreatitis
- Septic shock
- Paralytic ileus
- Ascites

The diagnosis of IAH requires either direct (invasive) or indirect (noninvasive) peritoneal pressure measurements. Clinical exam is highly subjective (<50% accurate) and should not be solely relied upon for diagnosis.

Consent

No specific consent is needed to measure IAP. The majority of critically ill patients will have had a urinary catheter placed previously.

Preparation and Procedure

- A consensus conference has recently defined a standardized approach for IAP measurement:

  IAP should be expressed in mmHg and measured at end-expiration in the complete supine position after ensuring

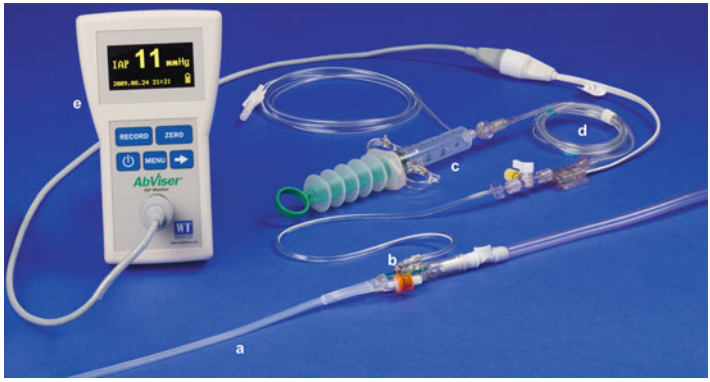

FIGURE 15.1 Equipment to measure intraabdominal pressure: (**a**) urinary catheter with; (**b**) side port for injection; (**c**) syringe attached to three-way-taps; (**d**) monitoring line with pressure transducer; (**e**) IAP pressure monitor (Reproduced with kind permission from Wolfe Tory Medical)

that abdominal muscle contractions are absent and with the transducer zeroed at the level of the midaxillary line. The reference standard for intermittent IAP measurement is via the bladder with a maximal instillation volume of 25 ml sterile saline.

- It is important to remember that
  - Saline should be warmed to body temperature prior to instillation as colder saline can cause reflexive detrusor muscle contraction, falsely elevating measurements.
  - Head-of-bed elevations >20° may result in spuriously high results.
- The following equipment is needed (see Fig. 15.1):
  - Indwelling urinary catheter with a side injection port,
  - Clamp or stopcock,
  - Pressure transducer.
- Serial measurements may be taken and averaged in order to reduce variability.

- It is recommended to measure IAP at least every 4 h. In a patient who is being actively resuscitated and is in a rapidly fluctuating physiologic state more frequent monitoring every 1–2 h may be appropriate.

Once the diagnosis of IAH (≥12 mmHg) is made, early surgical consultation is recommended. Although non-surgical interventions may succeed in lowering IAP, operative decompression is considered the gold standard rescue therapy should these interventions fail.

Several simple non-invasive interventions may be tried in the first instance:

- Evacuation of intraluminal contents: Gastric decompression via nasogastric or orogastric drainage is the simplest and least invasive way. Rectal enemas and tube decompression may also be attempted. Emptying and motility may be augmented through administration of promotility agents. Consideration may be given to colonoscopic decompression and temporary discontinuation of enteral feeding should the above measures fail to decrease IAP.
- Evacuation of intraabdominal space-occupying lesions: Percutaneous aspiration and catheter drainage of intraabdominal fluid (e.g. ascites, hemoperitoneum, intra-abdominal abscess) is an effective method of decreasing IAP. Image guidance using ultrasound or CT is strongly recommended.
- Improve abdominal wall compliance:
  - Patients with IAP need to have adequate sedation and analgesia. In some cases neuro-muscular blockade may be indicated (see Chap. 1).
  - All constrictive dressings such as abdominal binders should be removed if possible.
  - Patients positioned with a head-of-bed elevation should be switched to reverse Trendelenburg position.

It is important to bear in mind that these strategies are more likely to be effective as preventative measures before a raised IAP develops into ACS rather than treatment modalities.

Refractory ACS is most successfully treated by surgical decompression, but no precise threshold exists and clinical practice varies. The clinical picture with new onset of organ dysfunction in combination with a high IAP will guide decision-making.

In the absence of standardized guidelines, the following is a reasonable approach:

- IAP >25 mmHg, APP <50 mmHg: surgical decompression for all patients
- IAP >20 mmHg + new organ dysfunction or APP <50 mmHg: consider surgical decompression
- IAP >12 mmHg + new organ dysfunction: early surgical consultation and start of IAP treatment with above non-invasive measures.

Chapter 16
Ultrasound Guided Procedures

Sarojini David and Nicholas Screaton

Ultrasound guided procedures are an indispensible tool in intensive care. Its portability allows imaging without subjecting a critically ill patient to the risk of transfer to the radiology department. Appropriate use of ultrasound can expedite diagnosis and direct patient management. The basic skill required to detect common problems by ultrasonography can be acquired rapidly.

Nevertheless, ultrasound in the ICU can be challenging. Patients may be difficult to move and position, tubes and lines, surgical emphysema and dressings may all restrict probe positioning and limit views.

Technical Aspects

- Any modern ultrasound machine can be used. The multipurpose 3.5–5 Hz curvilinear probe is most commonly used for chest or abdominal studies due to its deeper

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Figure 16.1 Commonly used ultrasound probes (**a**) Linear 7–12 MHz probe; (**b**) 3.5–5 MHz curvilinear probe

acoustic penetration. Linear 7–12 MHz probes are used for superficial or vascular structures (see Fig. 16.1).

- The probe should be held like a pen. (see Fig. 16.2a, b)
- Ultrasound gel or sterile gel where appropriate optimizes contact between skin and probe.
- Imaging should be performed in both longitudinal and transverse planes.

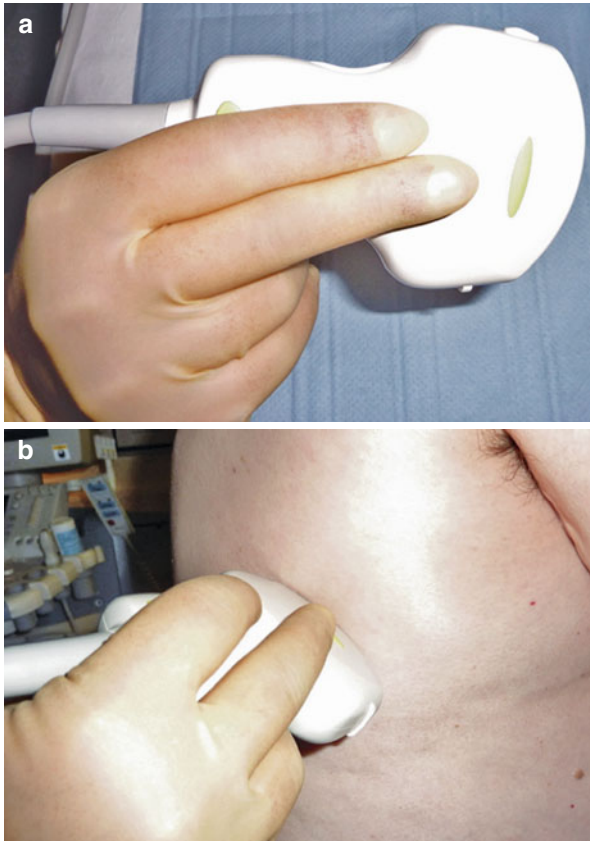

FIGURE 16.2 (**a**) holding the probe like a pen; (**b**) aligning it along the ribs for an intercostal approach

Patient Position

Good patient position may be difficult to obtain but is key to good image quality. Access to the relevant area should be optimized and unnecessary dressings removed or changed to transechoeic ones to facilitate visualization.

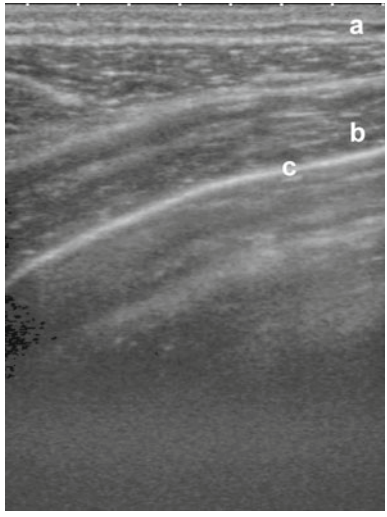

Figure 16.3 High-resolution view of normal lung with (**a**) heterogeneous soft tissue, (**b**) hypoechoeic muscle, (**c**) hyperechoeic pleura

Chest Ultrasound

It can help identifying lung pathology as well as being an important adjunct to therapeutic intervention.

- Normal ultrasound anatomy of chest:
  If it is not possible to sit the patient up they should be put in decubitus, supine or semi-recumbent position to achieve the best image quality. The normal chest wall appears as multiple layers of soft tissue of varying echogenicity. The high frequency probe better characterizes the muscular and subcutaneous tissues (see Fig. 16.3).
- Ribs cast dark echo shadows preventing further visualization (see Fig. 16.4). Normal aerated lungs are highly reflective and produce a 'comet tail' or repetitive horizontal artifacts (see Fig. 16.5). The diaphragm appears as a thin echogenic dome overlying the homogeneous liver and spleen (see Fig. 16.6).

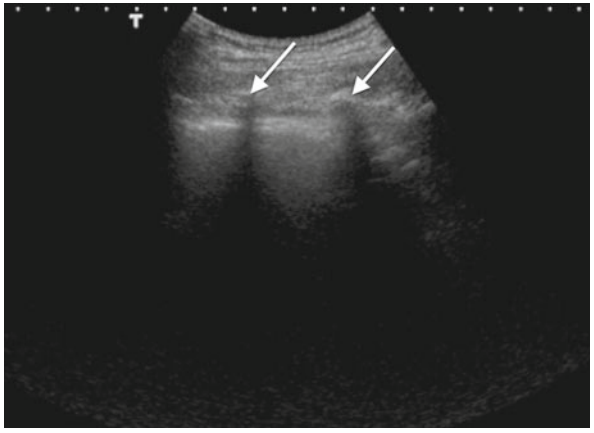

FIGURE 16.4 Acoustic shadowing from ribs (*arrows*)

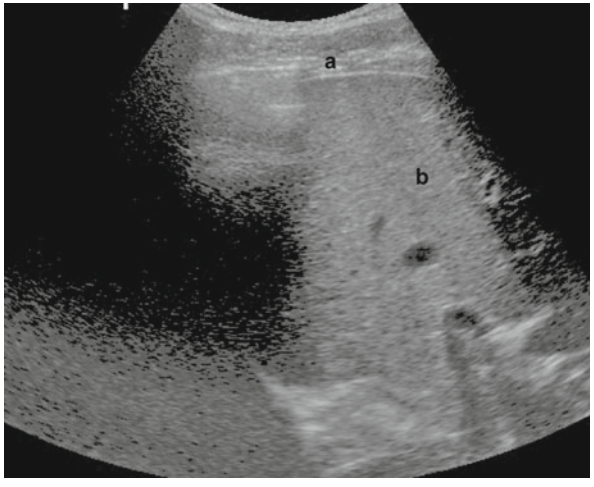

FIGURE 16.5 Air filled lungs prevent visualization of normal parenchyma, (**a**) subcutaneous tissue, (**b**) liver

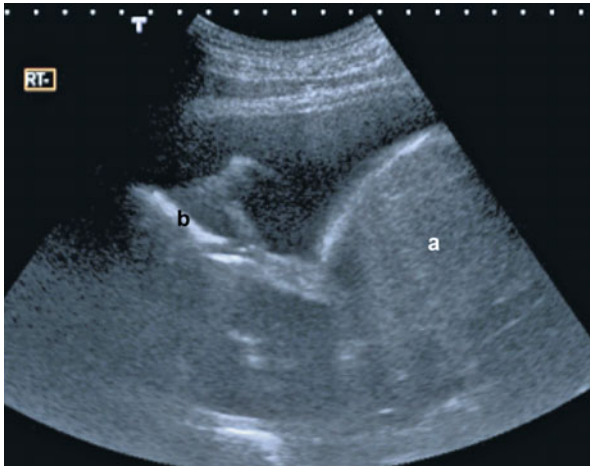

Figure 16.6 Echogenic right hemi-diaphragm separating effusion from the (**a**) liver, note (**b**) atelectatic lung

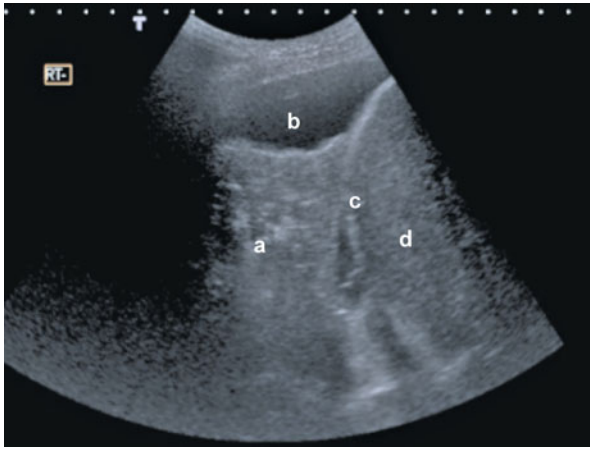

Figure 16.7 (**a**) Consolidated lung with (**b**) anechogenic parapneumonic effusion, identifying the (**c**) echogenic diaphragm permits differentiating consolidated lung from (**d**) liver

- Common abnormalities detected by chest ultrasound:
  - In consolidation displacement of alveolar air renders the lung solid with an echogenicity between that of normal liver and fluid. Air-filled bronchi within consolidated lung tissue produce echogenic linear branching reflections. The consolidated lung moves synchronously with respiration. It is important to confirm the position of the diaphragm in order to be able to differentiate between consolidated lung and liver (see Fig. 16.7). The presence of anechoic effusion aids orientation.
  - Portable chest X-rays, often taken supine, are limited in differentiating between atelectasis, consolidation and pleural effusions. This differentiation is straightforward on ultrasound.
    More than 60% of ICU patients have pleural effusions of various causes. Ultrasound appearance varies with the nature of the collection. Transudates caused by heart failure, renal failure, hypoproteinemia and uncomplicated parapneumonic effusions give rise to simple effusions.
    A simple effusion is typically anechoic (black) and unrestricted (see Fig. 16.8). Complex effusions mostly result from empyema, hemothorax or chylothorax. These fluid collections typically contain multiple septations and echogenic debris (see Fig. 16.9).
    Ultrasound guided drainage is useful in the management of complex pleural fluid but heavy septation may limit its effectiveness.

- Ultrasound guided drainage of pleural effusions:

  Preparation

  - If not sedated and / or intubated and ventilated the indication, procedure and potential complications should be explained to the patient. Drainage of large effusions does not require real time ultrasound guidance. However, the best site for the drain insertion can

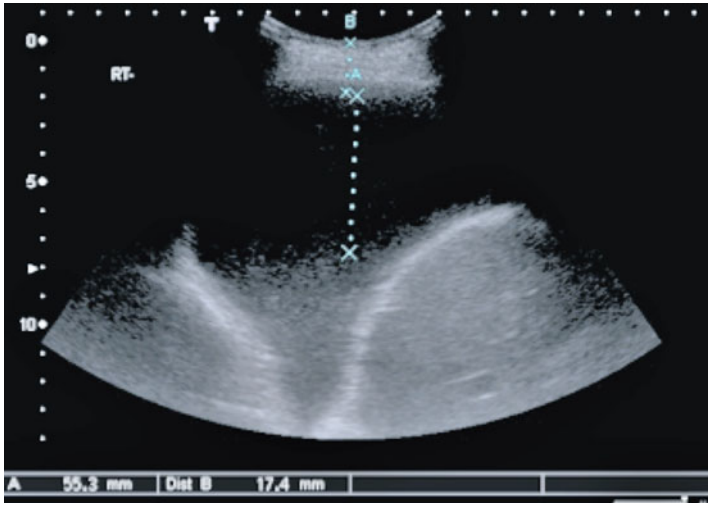

Figure 16.8 Large simple anechoic effusion, note the measurement from skin and maximum depth of effusion for drainage purposes

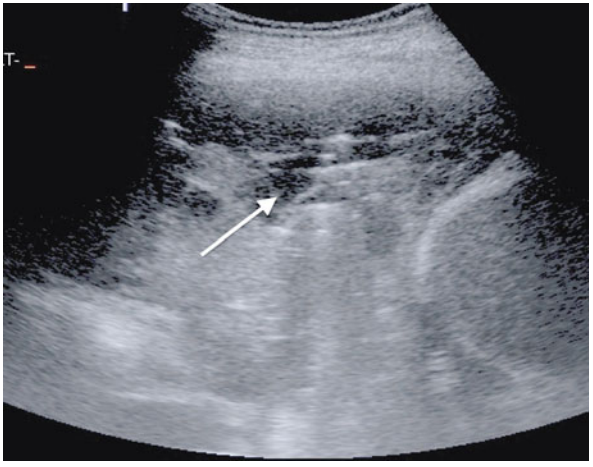

Figure 16.9 Complex effusion with septation (*arrow*) and echogenic debri in keeping with empyema

be identified and marked and the maximum fluid depth can be noted using ultrasound prior to the procedure.
- Where appropriate, any coagulopathy or platelet defect should be corrected.
- The most recent chest X-ray should be reviewed to check for the size of the effusion.
- Deep infiltration with local anesthetic (usually lignocaine 2%) generally makes the procedure tolerable for conscious patients. This may be supplemented with sedation for some individuals (see Chapter 1).
- Just as the insertion of chest drains (see Chapter 10), ultrasound guided drainage of pleural effusions is a clean procedure. The operator should scrub and wear gown, hat, mask and sterile gloves.
- Either a closed drainage system or a system with an underwater seal can be used to connect the drain to. Both will have to be tested prior to the procedure.
- The required instruments and equipment have to laid out on a sterile procedure trolley (see Fig. 16.10).
- The ultrasound probe is fed into a sterile sheath and placed onto the procedure trolley.
- Patient is positioned semi-recumbent for optimal access.

Procedure

- The chest wall is prepared with an antiseptic solution and surgical drapes are applied exposing the previously marked area.
- The curvilinear probe is aligned parallel to the ribs and
  - the maximum depth of effusion is identified,
  - the skin to pleural distance is measured using electronic calipers,
  - note is made of the costophrenic angle and the diaphragm to avoid injury to liver and spleen.
- Depending on the size of the effusion puncture and aspiration can either be performed "blindly" after the site has been correctly marked or under real time ultrasound guidance keeping the needle tip continually visible to avoid visceral injury.

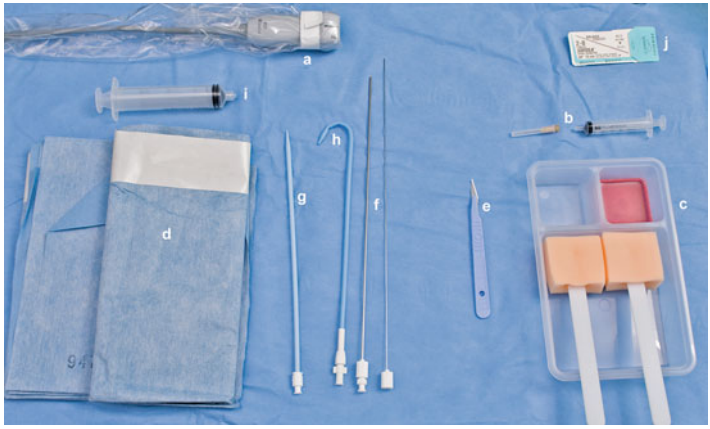

Figure 16.10 Procedure trolley for chest drain insertion under ultrasound guidance: (**a**) ultrasound probe in sterile sleeve, (**b**) syringe and needle for local anesthetic, (**c**) tray with antiseptic skin prep and applicators, (**d**) sterile drapes, (**e**) scalpel, (**f**) puncture needle with guide trocar, (**g**) dilator, (**h**) multi-orifice catheter, (**i**) 30 mL syringe for aspiration of pleural fluid, (**j**) suture

- After infiltration with sufficient local anesthetic the 16/18 G sheathed trocar needle attached to a 10 mL syringe is advanced along the chosen tract while gently aspirating.
- Once an adequate needle position is confirmed by fluid aspiration, the outer sheath is advanced from the trocar and needle removed.
- The guide wire is passed through the sheath and coiled in the pleural space. After the sheath has been removed, the dilatators are passed over the wire until the tract is sufficiently big for the catheter.
- The catheter of choice for simple effusions is a 8 or 10 F multi-side-hole pigtail. Complex effusions may require larger bore lumens to facilitate adequate drainage. The catheter is railroaded over the guide wire ensuring that all side holes are positioned within the pleural space. The guide wire is subsequently removed.

- The catheter is secured by means of a fixation device or suture and connected to the drainage system.
- The relevant samples can be obtained during the procedure.

Complications

- The risk of complications of chest drain insertion is lower when image guided than performed blindly. Ultrasound guidance is recommended in several guidelines. Nonetheless complications of this technique have been described including vascular injury, pneumothorax and infection.

Abdominal and Pelvic Ultrasound

Abdominal ultrasound is most commonly used to assess and drain suspected collections and to exclude obstructive causes of renal or hepatic dysfunction.

- Normal abdominal ultrasound anatomy:
  - Liver and biliary tree
    Normal liver parenchyma is homogeneous in echo texture and surrounded by an echogenic capsule. The liver parenchyma is interspersed with anechoic tubular vasculature. The common bile duct measures 3–4 mm, while the extra hepatic bile ducts are not normally visualized. The intrahepatic portion of the bile duct can be easily demonstrated just anterior and slightly right of the portal vein. The normal gall bladder is thin-walled (<3 mm) and anechoic (see Fig. 16.11).
  - Renal tract:
    Normal adult kidneys measure between 9 and 12 cm in length. The renal cortex is usually of slightly lower echogenicity than liver or spleen. At the renal hilum the renal artery and veins may be identified together with the renal pelvis. The renal pelvis is anechoic when visible and surrounded by echogenic renal sinus fat and hypoechoic medullary pyramids (see Fig. 16.12).

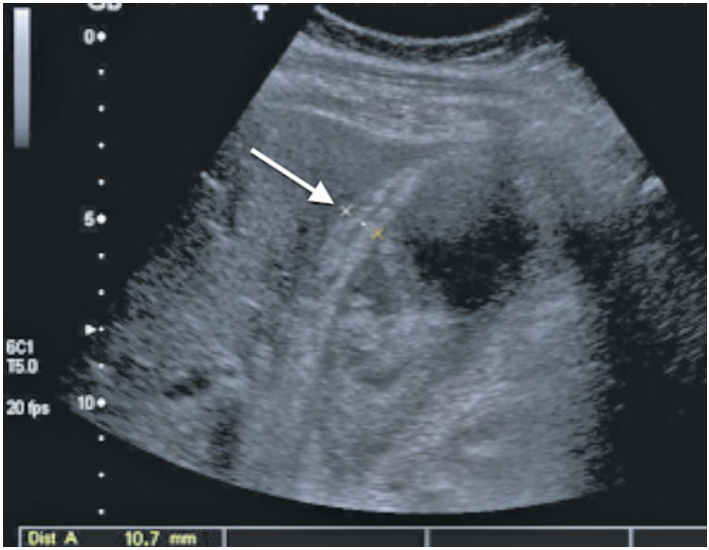

FIGURE 16.11 Normal gall bladder, wall thickness <3 mm (*arrow*)

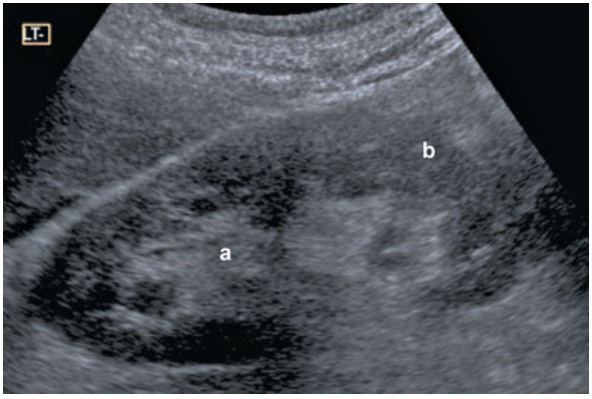

FIGURE 16.12 Normal kidney with smooth outline, hypoechoic cortex (**a**) and echogenic intra-medullary fat (**b**). Renal pelvis is not normally seen in an unobstructed kidney

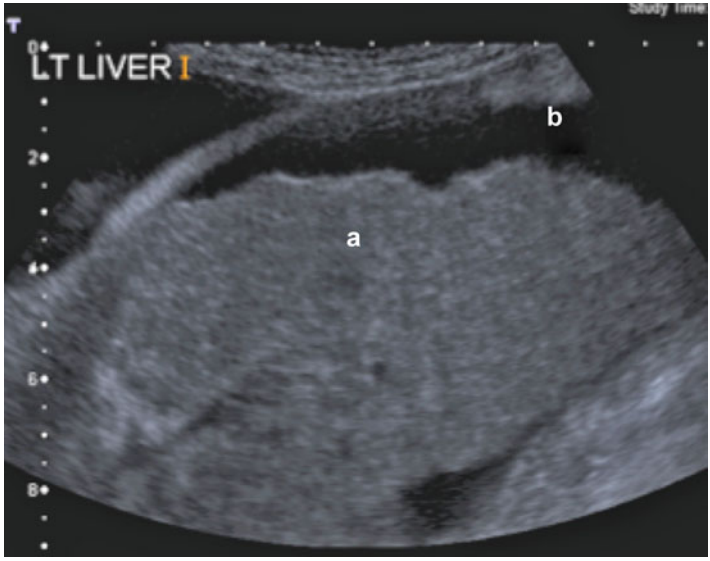

FIGURE 16.13 (**a**) Cirrhotic liver with irregular edge and (**b**) associated ascites

The distended bladder has a thin (<3 mm) hyperechoeic rim and contains anechoic urine. The bladder volume can be easily measured.

- Common abnormalities detected by abdominal ultrasound:
  - Ascites and collections:
    Ultrasound is useful in both diagnosing and guiding the drainage of fluid. However, the evaluation of ascites is restricted to areas not impeded by bowel gas. Small amounts of ascites typically collect in the hepatorenal recess or perivesical region (see Fig. 16.13). Larger collections of ascites tend to be in more dependent region such as the flanks (see Fig. 16.14).
    Post-operative and infected collections are most commonly found in dependent locations. They are often loculated and contain echogenic debris.

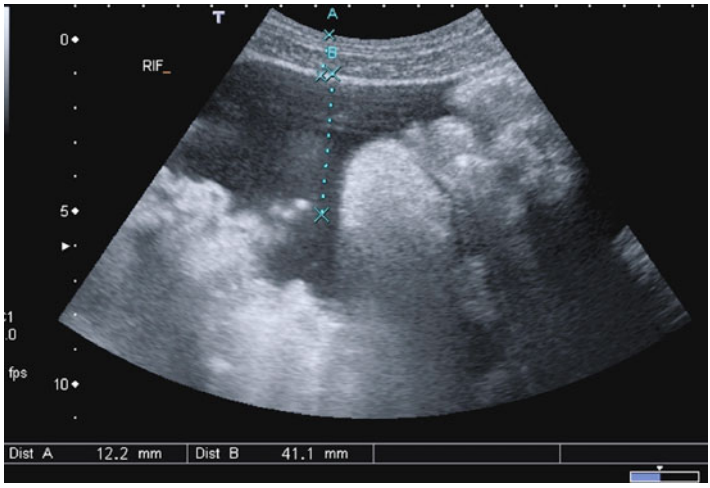

FIGURE 16.14 Ascites in the right flank, note the measurement from the skin to the maximum depth of the collection for drainage purposes

  - A thickened gall bladder wall often results from hypoproteinemia or cholecystitis. Although cholecystitis is most commonly due to stones, acalculous cholecystitis regularly occurs in critically ill patients (see Fig. 16.15).

- Ultrasound guided drainage of abdominal fluid:
  Drainage of ascitic fluid can be performed using the same technique described above for pleural drainage. A suitable site, usually in right of left iliac fossa or flank, is identified, the maximum fluid depth is assessed making sure there is sufficient clearance from other structures (see Fig. 16.14). Real time guidance can be used to avoid visceral or bowel injury.

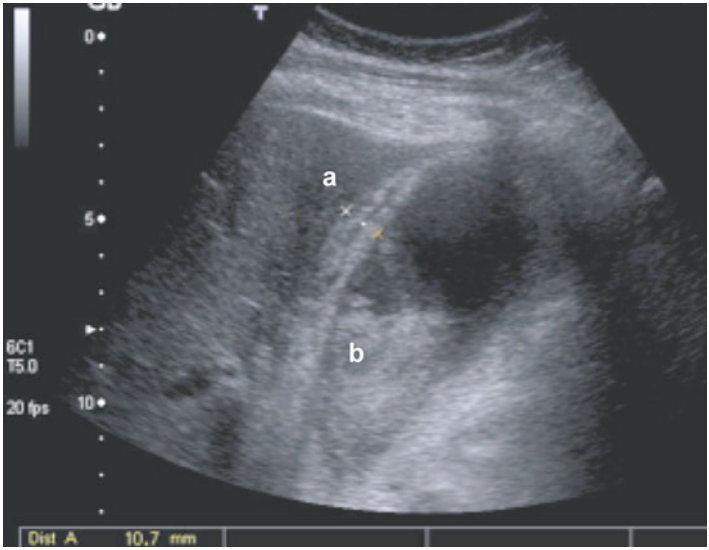

FIGURE 16.15 (**a**) Distended, edematous and thickened gall bladder wall containing, (**b**) echogenic sludge in keeping with acalculous cholecystitis

Chapter 17
Renal Replacement Therapy

Adrian James Varley

Modern continuous renal replacement therapy (RRT) allows rapid, safe and efficient correction of the biochemical and volume derangements associated with acute kidney injury (AKI). Recent work on AKI has highlighted the independent association with mortality it engenders, and there has been a move to instituting replacement techniques earlier as a result.

Indications

- Hyperkalemia
- Metabolic acidosis
- Volume overload
- Dialyzable drug or toxin removal; this requires that the toxin is of a low molecular weight, minimally protein bound and has a small volume of distribution
- Symptomatic ureamia including ureamic encephalopathy and pericarditis
- Severe dysnatraemia

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Physiology of Renal Replacement Therapy

- The clearance of solute in hemofiltration is determined by:
  - Blood flow through the filter – is governed by Poiseuille's law, $Q = (\pi \times r^4 \times P)/(8 \times \eta \times L)$, where Q = flow rate, r = radius of the tubing, P = pressure difference between the ends of the tubing, η = viscosity, L = length of tubing.
  - Transmembrane pressure (TMP) – is determined by the difference between the inlet and outlet pressure of the filter, and the absolute hydrostatic pressure of the filtrate side of the membrane.
  - Filtration fraction – is determined by the TMP, surface area of the filter, permeability of the membrane, plasma oncotic pressure and the hematocrit.

- Clearance of solute in hemodialysis is determined by:
  - Dialysis flow rate
  - Blood flow rate
  - Surface area of the filter
  - Dialysis fluid composition

Some proteins (Fibrinogen, Albumin) adhere to the extracorporeal circuit and are subsequently lost through adsorption. It is of minimal clinical significance unless the circuit needs frequent changing.

Common Modes of RRT

Intermittent hemodialysis is the most efficient renal replacement technique, but rarely utilized in the ICU. It allows large amounts of fluid to be removed very quickly while electrolyte abnormalities can be corrected rapidly. However, the majority of critically ill patients will not tolerate these enormous shifts. It appears that the commonly seen hypotension may worsen the renal injury by further ischemic insults.

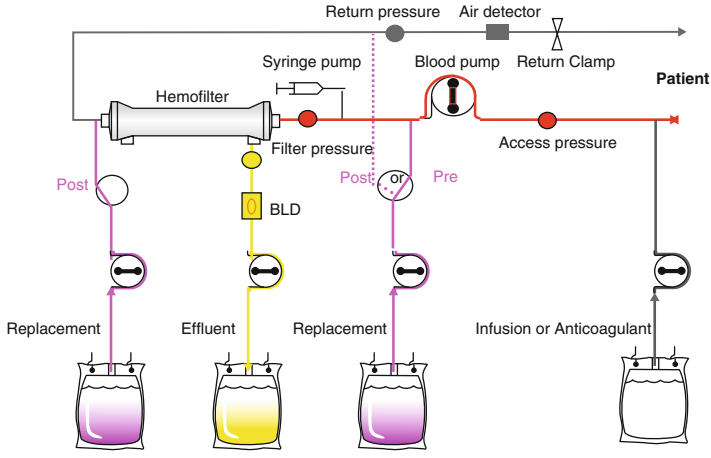

FIGURE 17.1 Schematic diagram of CVVH circuit (Reproduced with kind permission from Gambro)

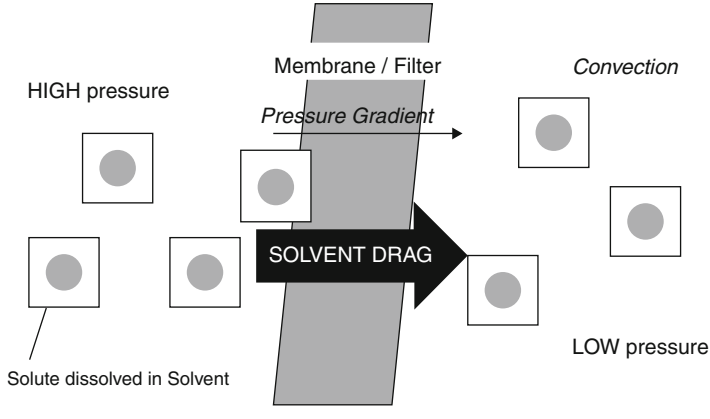

FIGURE 17.2 Schematic diagram of flow across a membrane in CVVH

- Continuous Veno-venous Hemofiltration (CVVH) (see Fig. 17.1) – requires a flux of water driven by hydrostatic pressure across a semi-permeable membrane. Solute is removed by solvent drag, a process known as known as convection (see Fig. 17.2). The fluid produced is known as ultrafiltrate. This

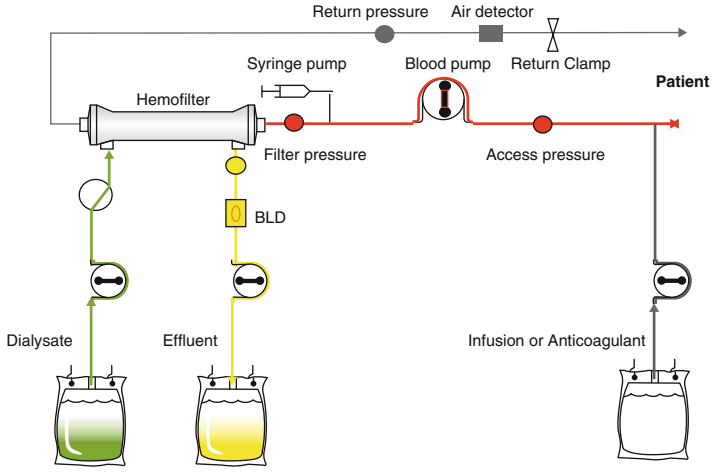

FIGURE 17.3 Schematic diagram of CVVHD circuit (Reproduced with kind permission from Gambro)

reflects elimination of substances in the kidneys. Clearance is higher for middle molecular weight molecules, 500–5,000 Da, such as the cytokines involved in sepsis.

- Continuous Veno-venous Hemodialysis (CVVHD) (see Fig. 17.3) – relies on blood flowing in a counter-current fashion to the dialysate, separated by a semi-permeable membrane. Solute is removed by diffusion (see Fig. 17.4). Clearance is highest for lower molecular weight molecules, <500 Da, such as urea and creatinine.
- Continuous Veno-venous Hemodiafiltration (CVVHDF) – combines both modalities and allows for the most rapid clearance of a range of solutes.

Preparation

- Vascular Access – RRT in the ICU is usually done via a 10 or 12Fr double lumen catheter, allowing flow rates of 250 mL/min or more (line placement see Chap. 5). Problems with flow rates and catheter fracture due to kinking can be encountered when the subclavian vein is used.

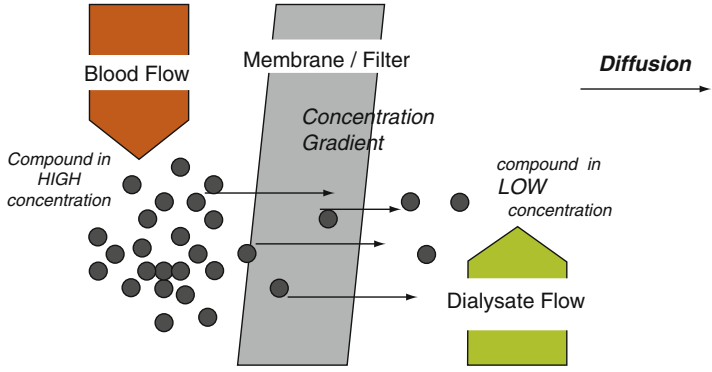

FIGURE 17.4 Schematic diagram of flow across membrane in CVVHD

- Replacement fluids – are commercially available and contain sodium, calcium, magnesium and a buffer. Lactate is commonly used as buffer, bicarbonate can be used for patients unable to metabolize lactate. Patients on prolonged RRT may need electrolytes and trace elements replacing.
- Pre/post dilution – replacement fluid can be infused into the circuit before the filter (pre-dilution) or after the filter (post-dilution). Pre-dilution is associated with increased clearance of urea (due to diffusion of red cell urea into the plasma) and may extend filter life due to a reduction in hematocrit. On the other hand, pre-dilution often leads to a reduction in the clearance of most other solutes as it decreases their concentration.
- Filters – vary in their materials (typically acrylonitrile and sodium methallyl sulfonate copolymer), construction (hollow fiber versus flat plate membranes) and surface area. Larger surface area filters are associated with a higher filtration fraction and less hemoconcentration, but require a higher priming volume and have a slower blood flow. The typical adult filter has a surface area of 0.60–1.2 m^2.
- Anti-coagulation – is necessary to prolong filter life. Anticoagulation can be either systemic or via the renal replacement device, with the anticoagulant administered

into the circuit pre-filter. Heparin is the standard anticoagulant, but can be contra-indicated in severe trauma, increased bleeding risk or in patients with heparin-induced thrombocytopenia. If heparin is used systemically the APTT should be limited to 1.5 times normal.

- Flow rates – Solute clearance is determined by the filtration or dialysis rate. This in combination with the amount of fluid replacement will determine the overall fluid balance. High flow RRT has not been shown to have significant benefits but an increased risk of hypophosphatemia. Therefore a standard dose, expressed as effluent flow rate of 25 mL/kg/h, is recommended on current evidence.

Complications

- Associated with the extra-corporal circuit
  - Circuit clotting can't always be avoided. Careful monitoring of anticoagulation helps prolong the lifespan of the circuit.
  - Bleeding is a risk in all anticoagulated patients. If the risk is deemed too high, continuous RRT can be run without anti-coagulation, accepting more frequent circuit changes.
  - Embolization is rarely seen and can be avoided with anticoagulation.
  - Access related complications see Chap. 5.
  - Hypothermia can be avoided by insulating the lines and/or by using a device with an integrated warmer.
- Associated with RRT
  - Initial hemodynamic instability as a result of the volume loss when priming the filtration circuit can be treated with a fluid bolus or vasopressors.
  - Thrombocytopenia is most commonly caused by contact activation.

- Filtration and dialysis will remove therapeutic drugs and trace elements. Drug doses and also nutrition might have to be adapted accordingly.
- Electrolyte abnormalities and over-correction can be avoided by regular checks.
- Disequilibrium Syndrome is rarely seen when using the described techniques. However, clinicians need to be aware of this syndrome, which is characterized by acute neurological dysfunction as a result of cerebral edema, thought to be caused by rapidly changing osmotic gradients.

Chapter 18
Lumbar Puncture

Sebastian Schulz-Stübner

The volume of cerebrospinal fluid (CSF) in a healthy adult is approximately 150 mL. Depending on the patient's position and body habitus the normal opening pressure during lumbar puncture ranges between 5 and 18 cmH_2O. There should be no red blood cells in normal CSF and less than five white cells. Normal glucose concentration is 2.2–3.9 mmol/L, lactate 1–2 mmol/L, albumin 0.06–0.45 g/L and IgG 0.009–0.057 g/L. Lumbar punctures (LP) can be performed for either diagnostic or therapeutic reasons.

Indications

- The most common indications for a diagnostic LP are suspected
  - Meningitis
  - Multiple sclerosis
  - Subarachnoid hemorrhage
  - Malignant meningeal infiltration.

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- The most common therapeutic interventions using LP are
  - Release of elevated CSF pressure in patients with malabsorption hydrocephalus
  - Insertion of a drainage catheter after subarachnoid hemorrhage or in patients with a traumatic CSF leakage through the ear or nose
  - Insertion of a drainage catheter prior to certain neurosurgical procedures or surgery of the descending aorta.

Contraindications

- Coagulopathy is a relative contraindication. There are no clear cut recommendations regarding critical values of platelet count, INR or PTT as they exist for elective spinal anesthesia. When weighing risks and benefits
  - a platelet count $<20 \times 10^9$/L is viewed as an absolute contraindication,
  - a platelet count $>50 \times 10^9$/L and an INR <1.5 are considered safe by the majority of authors.
- Additional medications such as anti-platelet agents or low molecular weight heparin need to be taken into account. Intravenous heparin administration should be stopped 4 h before the procedure.
- If the patient shows symptoms of elevated intracranial pressure a CT or MRI scan should be performed prior to a lumbar puncture to exclude the possibility of uncal herniation when the lumbar CSF pressure is suddenly decreased.
- Infection of the puncture site is a contraindication.

Consent

The patient's neurological state permitting, the procedure, rationale and its risks should be explained. Whenever possible the procedure should be described to patients to ensure their co-operation.

The risks include

- Permanent nerve damage
- Bleeding
- Infection
- Postprocedural headache.

Preparation

Anatomic landmarks are normally identified easily. In patients with previous back surgery and complex instrumentation, severe scoliosis or in the morbidly obese ultrasound or fluoroscopic guidance might be needed and should be arranged in advance.

Very anxious, awake patients can benefit from being given some sedation before the procedure (see Chap. 1).

For a diagnostic lumbar puncture it is deemed sufficient if the operator wears hat, mask and sterile gloves. If a catheter is inserted a sterile gown should be worn in addition.

A procedure trolley with all necessary equipment should be set up (see Fig. 18.1). In addition at least three bottles (microbiology, biochemistry, cytology) for CSF samples and further tubes for special tests as needed should be prepared.

Positioning and Identification of Puncture Site

- Owing to the anatomy of the lumbar spine (see Fig. 18.2) careful patient positioning will make the procedure less traumatic for the patient.
- Awake and cooperative patients can be encouraged to sit at the side of the bed or operating table. Shoulders and hips have to be aligned vertically in order to prevent torsion of the spine (see Fig. 18.3). The legs can be allowed to dangle or rest on a stool. An assistant, who will ensure that the patient arches their back “like a cat”, best supports the patient’s arms. It is important to prevent the patient from moving forwards or backwards in case of unexpected fainting or a startling response during the procedure.

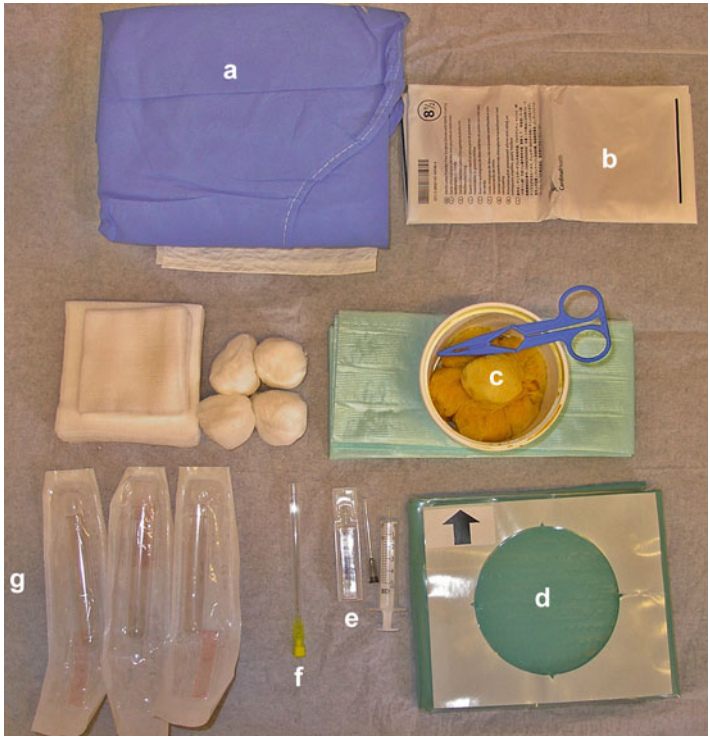

Figure 18.1 Lumbar puncture kit, (**a**) sterile gown, (**b**) sterile gloves, (**c**) skin prep, (**d**) sterile drapes, (**e**) local anesthetic, syringe, hypodermic needle, (**f**) LP needle, (**g**) CSF collection pots

- Uncooperative or sedated patients will be positioned in the lateral decubitus position (see Fig. 18.4). When using this position it is important to remember several things to make the procedure easier for the operator and easier to tolerate for the patient:
  - keep the patient close to the edge of the bed,
  - make sure head and legs are flexed,
  - keep the hips at 90°,
  - avoid rotation of the shoulders.

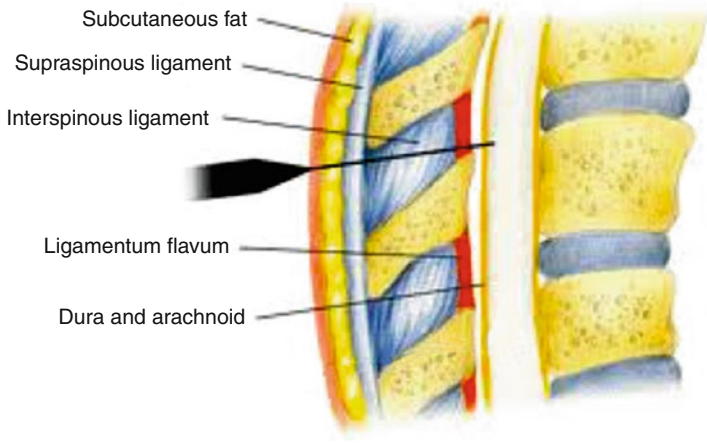

FIGURE 18.2 Anatomy of the lumbar spine

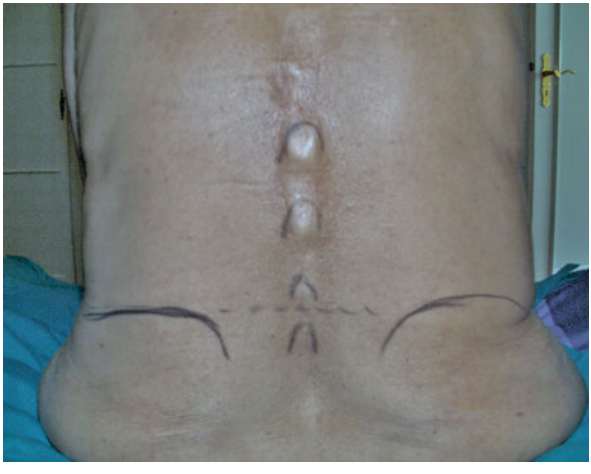

FIGURE 18.3 Patient in sitting position, note Tuffier's Line between iliac crests at L4/5

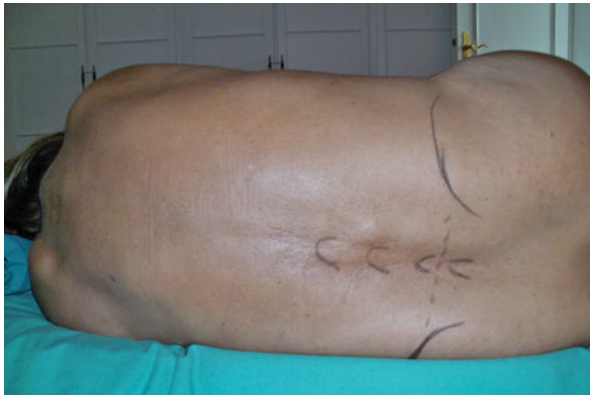

Figure 18.4 Patient in lateral decubitus position

- After positioning, "Tuffier's Line" between the iliac crests is identified. It marks the level of L4/5 (see Fig. 18.2). It is worth bearing in mind that
  - there is a discrepancy between the identified intervertebral space and the actual anatomical space in about 50% of cases
  - the conus medullaris ends at L1 in about 94% of patients. It may come down all the way to L5 in the remaining 6%!
- Once L4/5 has been identified, the intervertebral space is palpated and marked by creating a small subcutaneous vacuum. This is done by pulling the plunger of a syringe and then removing the needle of the subcutaneous tissue. A small skin wheel remains visible. Although popular, marking the site with deep pressure of the doctor's fingernails can lead to skin damage, thus possibly increasing the infection risk.

Procedure

- After thorough skin disinfection and sterile draping, the skin and underlying tissue are infiltrated with local anesthetic (usually 3–5 mL of lignocaine 1%).

- The spinal needle is introduced through the skin. 22 G spinal needles are commonly used to allow easy flow of CSF. If small-bore spinal needles (25–27 G) are used, an introducer needle will be needed to avoid bending it. Puncture with a 25–27 G needle has a lower incidence of headache, however at the expense of a more difficult and slow CSF aspiration. For catheter placement an 18 G Touhy needle and a standard epidural catheter set are used.
- For the midline approach the needle is advanced at 10–15° to the skin. In case of bone contact the needle is withdrawn without exiting the skin and re-advanced at a different angle. It is worth remembering that a small change in angle on the outside produces a significant change in the position of the needle tip at a depth of 4–6 cm. If bone contact is made again, reassess the insertion point.
- In elderly patients or those with calcified ligaments the paramedian approach might be beneficial. The spinous process of L4 or L5 is palpated and the needle inserted 1 cm lateral and 1 cm inferior to the spinous process. The needle is directed towards the midline.
- If the patient complains of back pain while advancing the needle an additional small amount of local anesthetic can be injected through the spinal needle.
- In case of radicular pain or paresthesia the needle should be repositioned or withdrawn until the pain or paresthesia is gone.
- The penetration of the ligamentum flavum and shortly after of the dura is often felt by the operator as a distinct change in tissue resistance. At this point the stylet is removed and the needle advanced until free flow of CSF occurs. When the dura is perforated, the patient might experience a brief painful sensation and occasionally a vagal response can occur.
- Let the CSF drip freely into the sample bottles. If there is some fresh blood in the first bottle, this is most likely puncture related and is not indicative of subarachnoid hemorrhage.
- If the use of a catheter is planned, it can be threaded into the intrathecal space now. It should penetrate the space by about 5 cm. Catheters should be tunneled if intended for use more than 3 days.

- Once the needle has been withdrawn and a sterile dressing has been applied the patient is repositioned comfortably.

Complications

Patients should be monitored with repeated neurological examinations for 24 h after the procedure. Bed rest is not necessary and has not been shown to prevent post puncture headache. In case of loss of motor function in the legs or loss of sensation with or without severe backache an emergent MRI scan of the lumbar spine has to be performed to rule out a spinal hematoma. Because of underlying neurological diseases the differential diagnosis can sometimes be difficult.

- Epidural abscesses are very rare but can occur with a time delay of up to several weeks and present with atypical symptoms. The history of a lumbar puncture might be the only clue to initiate MRI diagnosis in otherwise unclear cases of backaches.
- Mild backache immediately after the procedure occurs frequently and responds well to NSAID treatment.
- Headache post dural puncture is characterized by severe positional pain. It is described as dull and throbbing when upright or sitting and usually almost vanishes in supine position. The presumed mechanisms involve some degree of intracranial hypotension related to CSF leakage through a dural tear but also a direct effect on the dural fibers. If a post-dural-puncture headache is suspected initial treatment includes bed rest, hydration, NSAID and caffeine. If a severe headache persists for more than 24 h an epidural blood patch is indicated. 10–15 mL of the patient's blood are injected in the epidural space at the level of the original puncture. The headache is relieved almost immediately in most cases, confirming the diagnosis. An operator experienced in epidural anesthesia should perform this renewed procedure.The use of small bore, pencil point needles has been shown to reduce the incidence of post-dural-puncture headache.

- Other rare complications include subdural hematoma, vertigo, hearing loss, tinnitus, visual disturbances, meningitis or persistent radicular pain. Special neurological consultation and follow up is required in those cases.

Chapter 19
External Ventricular Drain Insertion

Marcus H.T. Reinges

The intracranial cavity has three main components, all of which are essentially non-compressible:

- Brain,
- Blood,
- Cerebrospinal fluid (CSF).

Because the skull is rigid, an increase in the intracranial volume leads to increased intracranial pressure (ICP). A normal adult produces about 500 mL of CSF inside the ventricular system each day. Any obstruction of CSF flow and/or resorption (acute hydrocephalus) is life threatening within minutes to hours.

Placing an external ventricular drain (EVD) is one of the most important neurosurgical procedures. If performed by an appropriately trained operator it has a high rate of functional accuracy and a low rate of associated mortality and morbidity.

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Indications

- Relieving of raised ICP or acute hydrocephalus as a common complication of:
  - Trauma
  - Subarachnoid hemorrhage
  - Intraventricular hemorrhage
  - Intracranial tumor
  - Meningitis or ventriculitis
- Measuring of ICP
- Sampling of CSF
- Administration of medication into the CSF

Consent

Patients for an emergency EVD insertion will usually be sedated, intubated and ventilated. On rare occasions an awake patient will have to undergo the procedure in the ICU. The procedure as well as risks and benefits should be explained to them. They should be informed about

- Bleeding,
- Infection,
- Blockage of the drain with the need for further intervention to replace it.

Preparation

- EVD insertion is a clean procedure, performed under sterile conditions. The operator should scrub and wear sterile gloves, gown, mask and hat. Prophylactic antibiotic cover is not routinely necessary.
- Generally, deep skin infiltration with a local anesthetic (usually lignocaine 2%) is sufficient to make the procedure tolerable for conscious patients.
- Additional sedation needs to be carefully weighed. Adequate analgesia and sedation (see Chap. 1) are particularly important in patients with elevated ICP following subarachnoid

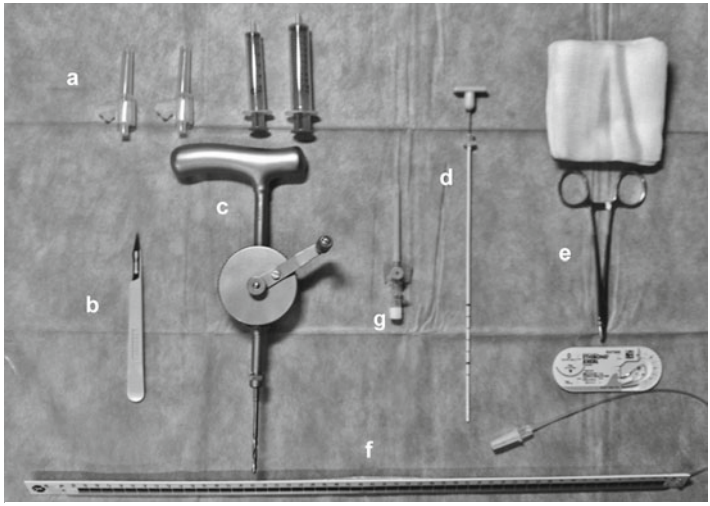

FIGURE 19.1 Set-up for EVD insertion: (**a**) needles, (**b**) scalpel, (**c**) 3 mm twist drill trephine with, large needle to perforate dura mater, (**d**) ventriculostomy catheter with trocar, (**e**) needle holder, suture, swabs, (**f**) ICP measuring system, (**g**) 14G cannula

or intracerebral hemorrhage to prevent re-bleeding. On the other hand sedation may lead to a further elevation of the ICP as a result of hypoventilation and increased $PaCO_2$.

- Good exposure, visibility, identification of craniotomy site and control of the direction of EVD insertion are mandatory to avoid complications.
- The necessary instruments should be laid out on a sterile procedure trolley before the intervention (see Fig. 19.1).
- The drainage and monitoring system (see Fig. 19.2) needs to be set up at the appropriate height, calibrated and flushed.

Positioning and Identification of Insertion Site

In most cases the EVD is placed into the frontal horn of the lateral ventricle of the non-dominant hemisphere.

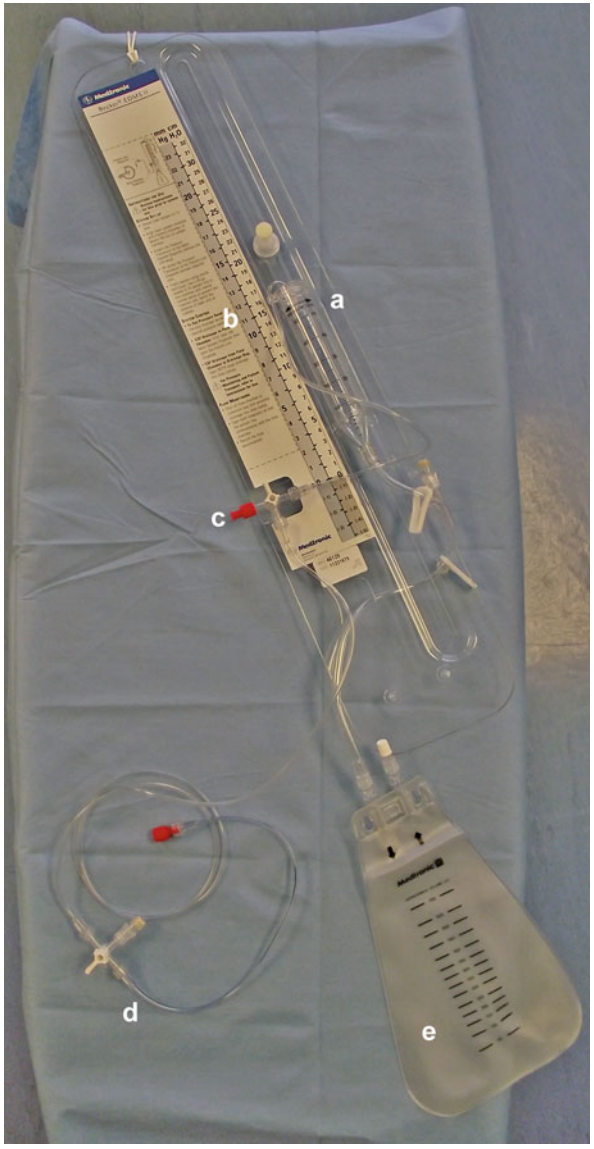

FIGURE 19.2 External drainage and monitoring system, (**a**) CSF drip chamber, (**b**) pressure scale (needs to be zeroed to the level of the patient's Foramen of Monro), (**c**) 3-way tap with port to connect to transducer and patient monitor, (**d**) extension to connect to patient, (**e**) CSF collection bag

If possible, the patient is placed in supine position with the head end of the bed elevated by 30–45°. The operator stands at the head end of the bed with the patient's head in a neutral position. It is important to exactly define the sagittal midline to avoid bleeding, infarction or air embolism by damaging the superior sagittal sinus. Asymmetry may be present in extracranial hematomas, depressed skull fractures or after neurosurgery.

Other ventriculostomy sites are parietal or occipital. In some cases it may be necessary to place the catheter in the dominant hemisphere or even several catheters in different sites simultaneously depending on pathology and shape of the ventricular system.

In the majority of adult cases the incision will be made on the right side, 2.5–3 cm from the midline and 1–2 cm anterior to the coronal suture, which is 10–11 cm upward from the nasion. The catheter is inserted pointing towards

- the ipsilateral external acoustic meatus in antero-posterior orientation and
- the medial canthus of the ipsilateral eye in latero-medial orientation.

The catheter is advanced about 6 cm from the surface of the skull into the frontal horn of the lateral ventricle.

Procedure

- After the insertion site has been identified the scalp is partially shaved and prepared with antiseptic solution.
- Where appropriate, the skin should be infiltrated with local anesthetic before a stab incision is made.
- The skull is opened using a 3–4 mm twist drill trephine, making sure that the direction of the burr hole points in the intended direction of catheter insertion.
- After perforating the dura with a 14G needle, the catheter is inserted using the landmarks described above for direction.
- The catheter is advanced to about 6 cm from the surface of the skull. In most cases there will be a loss of resistance after the ependyma has been perforated. At this point the

catheter tip lies within the ventricular system. Using this technique the catheter tip sits above the foramen of Monroe, avoiding contact with the choroid plexus.

- After the trocar is removed CSF should flow freely or at least be aspirated easily allowing all necessary CSF samples to be taken.
- The catheter is fixed at the insertion site or may be tunneled beneath the galea, brought out via a separate stab incision and sutured there.
- Since draining only a small amount of CSF can decrease ICP sufficiently the monitoring and drainage system should be attached as early as possible.
- The distal end of the catheter is usually connected to a flow chamber. As CSF flow depends on gravity, the level of the flow chamber ultimately determines flow. In most cases the flow chamber is positioned 10–15 cm above the level of the foramen of Monroe. This allows CSF flow to contain the ICP at 10–15 cm H_2O. The desired ICP has to be determined individually for each patient.
- If there is any doubt about the catheter placement the operator has to re-evaluate entry point and direction of insertion and possibly attempt a new drain. If it is still not possible to aspirate any CSF after a second drain has been inserted, a CT scan should be performed urgently to rule out misplacement or procedure-related intracranial bleeding. If necessary, another drain can be placed under CT guidance.
- After insertion of the EVD adequate hemodynamic monitoring and continuous clinical observation are mandatory. Especially the patient's neurological status and the amount of CSF drainage as well as the position of the flow chamber have to be assessed regularly.

Complications

- Infection can often be avoided by using immaculate sterile technique and needs early treatment to avoid developing into meningitis.

- Bleeding at the insertion site can mostly be dealt with by applying a pressure dressing but might occasionally require re-exploration.
- Any deterioration in the patient's neurological status may be indicative of injury to the brain and/or its blood vessels. This needs to be investigated urgently to avoid permanent neurological deficit or even death.
- Injury to the superior sagittal sinus or the venous lacunae near the midline can have serious consequences such as venous bleeding, stroke or air embolism. This can be avoided by careful identification of the insertion site.
- Over-drainage of CSF can lead to re-bleeding, especially in patients with aneurysmal subarachnoid hemorrhage or intracranial arterio-venous malformations. Careful repositioning of the flow chamber after each patient manipulation can help avoiding this potentially fatal complication.
- Any CSF leak at the insertion site needs immediate attention to avoid infection and over-drainage.

Chapter 20
Intracranial Pressure Measurement

Jessie Welbourne and Basil Matta

The intracranial pressure (ICP) is the pressure within the cranial vault exerted by the cerebro-spinal fluid (CSF), blood and brain. Some sources define ICP as the pressure exerted by CSF within the lateral ventricles. The normal value for ICP is 5–17 mmHg when supine.

Indications

- Any cause of potential increased intracranial pressure, commonly
  - Traumatic brain injury
  - Intracranial hemorrhage
  - Post neurosurgery
  - Non-neurosurgical causes such as hepatic failure.

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Measurement Systems

- Intraventricular catheter – a fluid coupled catheter and external pressure transducer is the 'gold standard' in ICP measurement (see Chap. 19).
- Intra-parenchymal monitors – these micro sensors can be placed into the parenchyma of the frontal lobes via a small burr hole. They may also be placed intraventricularly or in the extradural space. They are often inserted in an area of the brain that will reflect global ICP e.g. the contra lateral side rather than the penumbra of the lesion.
- Fiber-optic cable, such as the Camino transducer – a cable with a pressure transducer at its tip. Once in situ it may not be recalibrated.
- Implanted microchip transducer, such as the Codman micro sensor transducer – these are solid-state pressure transducers with a whetstone bridge strain gauge at the tip of a nylon tube. This may be passed directly into the brain parenchyma or via an intraventricular catheter. These systems are more accurate than intraventricular fluid coupled catheters and are associated with a lower risk of infection and hemorrhage. However, they may not be recalibrated once inserted and have been reported to underestimate very high ICP values.
- The LICOX probe is a three-lumen system, which can monitor ICP, brain tissue oxygenation and temperature.
- Extradural, subarachnoid and epidural monitors, such as the Richmond Screw or the Leeds Screw – these fiber-optic monitoring systems require a burr hole, the fiber-optic probe is placed via a skull bolt between the dura and the skull. These systems have become less common in the advent of intra-parenchymal probes.
- Non-invasive methods – trans-cranial Doppler measurement of blood velocity in the middle cerebral artery in conjunction with arterial pressure is being developed as a method of indirect ICP measurement.

The main advantages of the catheter based measuring systems are:

- Ability to sample CSF for investigation and therapeutic drainage
- Intrathecal administration of therapeutic agents
- Ability to re-zero in regular intervals.

These are offset by the high infection risk, particularly when the catheter left in situ for more than 5 days.
Intra-parenchymal devices have a lower infection risk and are not dependent on fluid coupling and therefore less susceptible to dampened waveforms and artifacts. Their main disadvantages are:

- Inability to recalibrate in vivo
- Baseline drift of the of the transducer, making replacement necessary
- Inability the drain CSF or inject drugs.

ICP Waveforms

The ICP waveform trace is affected by pulsation from intracerebral vessels and by changes in intrathoracic pressure relating to the respiratory cycle. The waveform shows three distinctive patterns.

- A-waves are plateau waves of 50–100 mmHg, lasting 5–15 min. They are associated with cerebral vasodilatation, poor cerebral blood flow (CBF) and poor intracerebral compliance.
- B-waves are <50 mmHg, last around a minute and are associated with changes in respiratory pattern and possibly with local variations in O_2 and CO_2 tension.
- C-waves are <20 mmHg, occurring approximately 5/min and are related to changes in vasomotor tone.

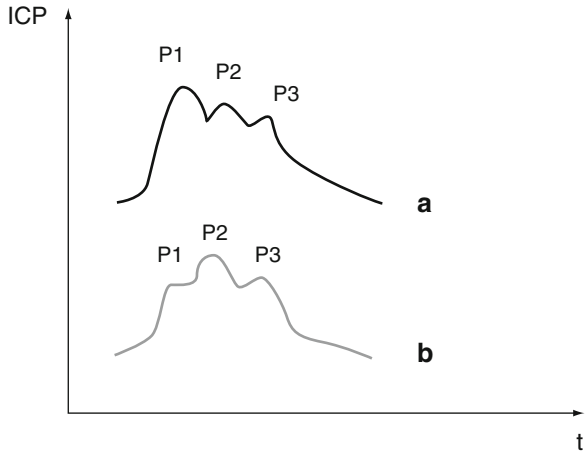

FIGURE 20.1 Intracranial arterial pressure trace, note the three distinct peaks. (**a**) compliant brain, (**b**) non-compliant brain

The intracranial arterial pressure trace is different from the commonly transduced arterial waveform (see Fig. 20.1). It has three distinct peaks

- P1 – called the percussive wave stems from the arterial pressure being transmitted through the choroid plexus.
- P2 – called the tidal wave. Its amplitude varies with brain compliance. In situations where the brain in non-compliant P2 may exceed P1.
- P3 – is the dicrotic notch.

Physiology of ICP

The skull is a rigid box with a fixed, incompressible volume. This means that the ICP is dependent on the volume of its contents, normally

- 50–70 mL blood,
- 50–150 mL CSF and
- 1.400 g brain tissue.

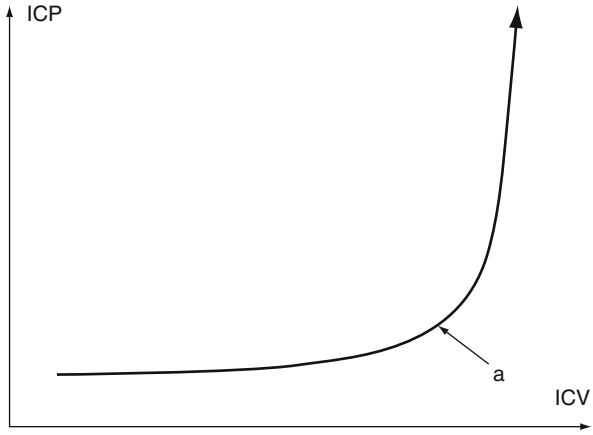

FIGURE 20.2 Intracranial pressure/volume relationship. The curve shows that there displacement of CSF and venous blood is able to compensate initially. Once these mechanisms are exhausted (**a**) small volume increases result in large pressure rises

The Monro-Kellie doctrine states that an increase in one of these components must be compensated for by a decrease in one of the other two components or ICP will rise. Initially the compensatory mechanisms

- increased CSF absorption into the spinal canal and venous circulation,
- compression of the venous sinuses

keep ICP within the normal range. They are able to compensate for volume changes of up to 100–120 mL. Any further rise in intracerebral volume after the compensatory mechanisms have been exhausted will result in a large increase in ICP, leading to edema and further increased ICP. Once ICP has risen above 20–25 mmHg the cerebral perfusion pressure (CPP) decreases, accelerating the downward spiral of hypoperfusion, ischemia, edema and cell death or herniation (see Fig. 20.2).

Factors Affecting the ICP

- Blood volume – e.g. venous obstruction, hypercapnia causing vasodilatation.
- Brain – e.g. edema, tumor, abscess or hematoma.
- CSF – e.g. obstruction of the ventricular system.

Management of Raised ICP

- Hyperventilation and CO_2 reduction result in cerebral artery vasoconstriction and decreased cerebral blood flow. However, cerebral vasoconstriction may cause cerebral ischemia and hypoperfusion associated with poor outcome when hyperventilation is prolonged or there is pronounced hypocapnia.
- Avoiding hypercapnia helps reducing cerebral edema.
- Positioning patients head-up by 10–15° allows improved venous drainage.
- Avoiding neck vein compression e.g. by endotracheal tube tapes helps increase venous drainage.
- Adequate oxygen delivery is essential and may be estimated with blood gas analysis, jugular bulb oxygenation or, where available, brain oxygen probe measurement. Cerebral oxygen metabolism (CMRO2) can be reduced with continuous infusions of i.v. anesthetic agents such as thiopentone or Propofol (see Chap. 1).
- Avoiding hyperthermia may reduce cerebral edema and cell damage with improved neurological outcome. When managing cerebral hypertension an initial temperature of <37°C is advised. Further active cooling to <35°C and subsequently 33° can be used where a raised ICP is refractory to other treatment.
- Tight blood sugar control has been shown to improve outcome.
- Mannitol is an osmotic diuretic used to treat acute raised in ICP by moving intracellular water into the vascular compartment, so reducing cerebral edema and lowering plasma viscosity.

- If an intraventricular drain is in situ drainage of CSF may be used to reduce ICP.
- When ICP remains raised despite optimized oxygenation, hyperventilation, sedation, CPP, diuresis and position a decompressive craniectomy may be considered. The relative benefits of further medical management vs. decompression are under evaluation.

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