Acute Care Surgery
Acute Care Surgery
Principles and Practice

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Preface

The genesis of this project is a direct result of the fact that there is no substantive textbook that addresses the full-spectrum of surgical emergencies. Even in a field in which there is a plethora of excellent textbooks on a variety of surgical topics (including trauma), there is no one reference book with a dedicated emphasis on both traumatic and nontraumatic conditions potentially necessitating surgical intervention in the acute setting. This project became even more unique when its stepwise development paralleled the evolution of a new specialty—acute care surgery. This was far from a serendipitous link. On the contrary, my editorial colleagues and I, along with many of the contributors, have recently been part of a major effort to build the foundation for this new specialty. As with any proposed new specialty, there have been a few rough interfaces with some of the other surgical specialties regarding the scope of practice of the acute care surgeon. Fortunately, the key to this conflict resolution will revolve around what is best for the patient. However, irrespective of these dynamics, there is a worsening crisis in acute care in this nation.

The anatomy of the textbook has five parts: Each chapter in the first two parts is preceded by a case scenario and multiple choice questions. At the end of each chapter in Part I (General Principles) and Part II (Principles and Practice of Acute Care Surgery: Organ-Based Approach), there is a critique for the case scenario and the associated answer. This format is designed to have the reader focus on a specific clinical management or system-based problem prior to reading the chapter. An entire section (Part III) is dedicated to administration, ethics, and law as it relates to issues and situations in the acute surgical setting. Another important feature of the book is the emphasis on system development (Part IV). Similar to the current trauma systems throughout the nation, there should be a more comprehensive network to facilitate optimal management of all surgical emergencies. These issues are addressed. Also, in the same section, there is a proposed training curriculum for Acute Care Surgery along with a model of an existing emergency surgical service that could serve as a foundation for the development of a more broad-based specialty. How our international colleagues are addressing emergency surgical needs is highlighted in the final section (Part V). Experts from three different continents provide focused insight into the intricacies of their respective systems with respect to acute care surgery.

In summary, this inaugural edition of this textbook is designed to be a comprehensive and definitive reference of the full spectrum of Acute Care Surgery. With contributions from the top experts throughout the world, I do feel this goal has been accomplished.

L.D. Britt, MD, MPH
Editor-in-Chief
A Tribute

This textbook is dedicated to one of the true giants in American surgery. He was a contributor to and a major inspiration for this project. If Dr. Claude Organ were to be described in one statement, it would be the following: “He was a monument to excellence.” With talents that transcended medicine, he was often highlighted as a legitimate renaissance man. Whatever he engaged in, Dr. Organ made better. It could be argued that the popular label “Midas touch” is more applicable to the life and times of Dr. Organ, for he was highly successful in all the arenas he entered. He consistently downplayed the litany of awards and accolades he accumulated.
throughout his illustrious career, including being elected Chairman of the American Board of Surgery, President of the American College of Surgeons, and Editor-in-Chief of the Archives of Surgery. He was the recipient of the highest award given by the American College of Surgeons: The Distinguished Service Award. Dr. Organ, the author of more than 250 scientific journal articles and book chapters, was an invited lecturer and visiting professor at many of the great institutions throughout the world.

This tribute provides only a glimpse of the impact that Dr. Organ had over his 78 year lifespan. Merely highlighting his professional career inadequately covers the full spectrum of his legacy, for the “big picture” view of Dr. Organ also includes that man who portrayed the consummate husband, father, grandfather, friend, colleague, and mentor. Perhaps his crowning achievement is his tremendously accomplished family. Even with this recognition, Dr. Organ would be quick to give the credit for the success of his seven children to his equally talented wife, Elizabeth (Betty). He stated on numerous occasions that his wife was the chief architect of the social and professional development of their children. Each child has become a prominent professional in various fields, including medicine, banking, art, and education. An argument could be made that this is one of the most successful American families – essentially, a guarantee that the Organ legacy will continue.

I am one of the many who was mentored by Dr. Organ and who profited from his endless wisdom and guidance. In fact, his last advice to me just prior to his untimely death was a firm charge to me to find a way to accelerate the completion and production of this textbook so that it would match the timing of the unveiling of the new specialty – Acute Care Surgery. With Dr. Organ being such a driving force in the first phase of the development of this project, my editorial colleagues and I can think of no one more deserving of this tribute.

L.D. Britt, MD, MPH
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Initial Assessment and Early Resuscitation

Louis H. Alarcon and Andrew B. Peitzman

The purpose of this chapter is to describe the assessment and resuscitation of both acute care surgery and trauma patients. Although differences exist in the initial evaluation and management of these categories of patients, certain principles can be applied to all critically ill and injured patients. Both the similarities and the differences are addressed. The specifics of the subsequent management of these patients are discussed in other chapters.

During the initial encounter with a patient, determination of severity of illness, identification of life-threatening conditions, and resuscitation must occur. The Latin word resuscitare is the origin of the term resuscitation and means to reanimate or revive. Resuscitation implies restoring adequate tissue perfusion with oxygenated and nutrient-rich blood. As this chapter emphasizes, it is within the first minutes and hours of patient–physician interaction that subsequent organ dysfunction can be either aborted or allowed to progress. An essential tenet in the early management of the critically ill acute care surgery or trauma patient is immediate initiation of therapy to correct abnormal physiology, as evaluation and diagnosis proceed.

The classic approach taught to medical students in the evaluation of a new patient is to complete a detailed history and physical examination and then formulate a differential diagnosis. However, when dealing with the severely ill or injured patient, this approach is not appropriate. Recognition and treatment of life-threatening conditions may be necessary before a definitive diagnosis can be determined. This is the approach adopted by the American College of Surgeons in the Advanced Trauma Life Support (ATLS) course.1 This organized and prioritized philosophy can be applied not only to trauma patients but also to any critically ill surgical or nonsurgical patient.

Triage

The word triage is derived from the French word meaning “to sort.” In the context of medicine, it implies the sorting and classification of injured or ill patients according to the severity of illness and prioritization of care according to available resources. Historically, war has provided the impetus to develop and refine triage systems. The lessons learned from the triage and care of casualties of war were eventually adapted to civilian medicine.
Unique Aspects of the Trauma and Acute Care Surgical Patient

Trauma and acute care surgical patients present with acute anatomic and physiologic derangements that can be life or limb threatening. These problems often require immediate identification and treatment, making these patients very different from the patient who presents in a nonacute care setting. The early recognition that a patient is “sick” requires an astute clinician and can sometimes be made by quick examination of the patient. Aggressive and timely resuscitation efforts must be promptly initiated. It must be recognized that the patient has severe physiologic disturbances, and these need to be addressed before a definitive diagnosis can be entertained. This modus operandi, which places emphasis on physiologic stabilization rather than on exhaustive diagnostic maneuvers, is in contradistinction of the classic approach, which is to diagnose first and treat the definitive diagnosis. Thus, critical diagnostic and therapeutic decisions are made based on incomplete information.

Another aspect that makes these patients unique is that the acute nature of their illness allows little or no preoperative evaluation. Complete evaluation and optimization of cardiovascular and pulmonary status is not feasible. In addition, these patients often present with full stomachs and/or substance intoxication, which can complicate airway and anesthetic management. The patients may also have injuries that complicate airway management, such as head, cervical spine, maxillofacial, or tracheobronchial trauma. Perhaps contrary to Occam’s razor, trauma patients often have multiple injuries. However, these are not random and often do present in predictable constellations based on mechanism of injury.

Today, it is clear that the primary goal in the stabilization of trauma and critically ill surgical patients is correction of physiologic derangements. The sequential approach to patients condoned by the ATLS course can be applied to all cases of critically ill patients, acute care surgery, and trauma (Table 1.1). The goals of the primary survey are to identify immediate threats to life and to stabilize the patient. These may require laparotomy or thoracotomy, control of hemorrhage or gastrointestinal contamination, and transfer to the intensive care unit for further optimization of hemodynamics and tissue perfusion. Definitive correction of anatomic disturbances may often need to be postponed until physiologic stabilization has occurred (e.g., the damage-control laparotomy).

Systematic Evaluation and Treatment

The initial priorities in the management of all critically ill or injured patients are the same: verify the patency of the airway, ensure adequacy of breathing and ventilation, and restore circulation to vital organs. Airway, breathing, and circulation (commonly referred to as the ABCs) remain the basic tenets of life support. During the primary survey of the patient, life-threatening conditions are identified and treated immediately in this orderly fashion. This is an essential principle of the ATLS algorithm. In the first few seconds of the patient encounter, the gravity of the patient’s condition can be quickly ascertained; this brief assessment will dictate the tempo and aggressiveness of the resuscitation efforts. Patients should be categorized according to hemodynamic status: agonal, unstable, or hemodynamically normal. Terms such as hemodynamic stability should be avoided. While this phrase attempts to convey hemodynamic normalcy over time, it is more appropriate to accurately describe the patient’s condition and its variability over the period of observation.

The patient who is unstable hemodynamically is hypotensive, tachycardic, or both. This represents physiologic decompensation and should be recognized as such and corrected expeditiously. The agonal patient is clearly profoundly ill with obvious clinical signs of shock. Such patients will not tolerate inadequate treatment. Time wasted on simply diagnostic procedures will increase the likelihood of a poor outcome for such patients. All maneuvers must be potentially therapeutic. For example, if the agonal patient may have a pneumothorax or hemothorax, this should be diagnosed by chest tube rather than chest radiograph, providing both diagnosis and therapy.

Airway and Breathing

The airway is assessed first to ascertain patency. If the patient is able to speak clearly, the airway is not likely to be in immediate threat. However, repeated reassessment is essential. Continuous determination of arterial oxygen hemoglobin saturation via pulse oximetry serves as an adjunct to airway monitoring. However, changes in pulse oximetry temporally lag behind significant alterations in alveolar oxygenation and ventilation and cannot be solely relied on to make this detection in a timely fashion. Supplemental oxygen should be provided via a mask.

Table 1.1. Initial evaluation and management of critically ill or injured patients.

<table>
<thead>
<tr>
<th>Primary survey</th>
<th>Airway</th>
<th>Breathing</th>
<th>Circulation</th>
<th>Disability</th>
<th>Expose the patient</th>
<th>Resuscitation</th>
<th>Secondary survey</th>
<th>Definitive care</th>
</tr>
</thead>
<tbody>
<tr>
<td>Source: Data from American College of Surgeons Committee.</td>
<td></td>
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</table>
The basic airway management strategy is to relieve the airway of obstruction. In unconscious patients, the most common cause of airway obstruction is the tongue, which moves posteriorly against the pharyngeal wall. A Glasgow Coma Scale (GCS) of 8 or less strongly suggests the need for a definitive airway immediately. Other causes of glottic obstruction are secretions, blood, vomitus, teeth, and or foreign materials. Edema of laryngeal structures may also lead to airway obstruction, as is seen with anaphylaxis, thermal injury, smoke inhalation, or epiglottitis. Facial, mandibular, or tracheolaryngeal fractures may also compromise the airway and complicate the ability to establish a definitive airway. Partial airway obstruction is evidenced by gurgling, stridor, hoarseness, or choking. The use of accessory respiratory muscles, paradoxical respiratory effort, or gasping signifies respiratory distress due to impending airway obstruction. These patients should have definitive airway control with the placement of an endotracheal tube.

For many patients with airway obstruction, simple maneuvers may open the airway and improve the ability of the patient to ventilate. These maneuvers are designed to displace the mandible anteriorly, thus moving the tongue forward and alleviating the obstruction. The head tilt–chin thrust maneuvers may be used initially for non-trauma patients. The head tilt is performed by placing the palm of the hand on the patient’s forehead and the other hand behind the neck. The head is tilted posteriorly. The chin lift is done by hooking the second and third fingers beneath the chin, and pulling the chin upward, bringing the teeth to near occlusion. These maneuvers provide significant anterior displacement of the mandible and significantly open the glottis. To reemphasize, these maneuvers are contraindicated for patients who may have blunt cervical spine injury.

The jaw thrust is another maneuver that may relieve airway obstruction, and, if performed correctly, it can be done while maintaining cervical spine immobilization. By grasping the angles of the mandible and lifting anteriorly, the mandible can be displaced anteriorly without movement of the spine. For unconscious patients, these maneuvers in combination with an oropharyngeal airway can facilitate adequate ventilation with a bag-valve-mask device until definitive airway can be established. Appropriate head positioning and a tight seal of the mask on the face are critical for the success of this procedure.

Application of cricoid pressure, the Sellick maneuver, reduces but does not eliminate the risk of gastric insufflation, with subsequent vomiting and aspiration. Definitive airway management is best accomplished with tracheal intubation. The decision to intubate is made for patients who show signs of inadequate respiration despite the basic airway maneuvers described previously or for whom these interventions alone are unlikely to sustain adequate respiration (Table 1.2). The most experienced operator should be designated to perform this task, as patients often will not tolerate prolonged attempts at intubation. Placement of an endotracheal tube is the best method to oxygenate and ventilate a patient, and, once secured, the tube reduces the risk of gross aspiration of gastric contents compared with bag-valve-mask ventilation. The decision to secure the airway with a tracheal tube can be made by assessing a number of parameters: airway patency, adequacy of oxygenation, adequacy of ventilation, ability to protect the airway (level of consciousness), and overall severity of the patient’s condition. The preferred route for definitive airway control for most patients is the orotracheal route. The nasal route should be avoided in patients with potential basilar skull or facial fractures. The surgical cricothyroidotomy is employed when the orotracheal route has failed or is deemed inappropriate because of significant midface or mandibular injuries or bleeding. Plans and preparations should always be made for this eventuality, because orotracheal intubation is not always successful.

The key to successful tracheal intubation is preparation of the patient and of the necessary equipment. Failure to position the patient appropriately or to test and prepare all necessary equipment is a frequent cause of unsuccessful intubation. For nontrauma patients, the head should be placed in the “sniffing position,” which is facilitated by placing a small pillow or folded towels behind the head (not the back). This position is absolutely contraindicated for trauma patients, who must be presumed to have a cervical spine injury. The need for inline cervical stabilization for trauma patients increases the degree of difficulty in intubating these patients.

The use of pharmacologic agents during intubation of patients remains an area of debate. The risks of sedative

<table>
<thead>
<tr>
<th>Table 1.2. Indications for endotracheal intubation.</th>
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</thead>
<tbody>
<tr>
<td><strong>Absolute indications</strong></td>
</tr>
<tr>
<td>Airway obstruction or near obstruction (e.g., stridor)</td>
</tr>
<tr>
<td>Apnea or near apnea</td>
</tr>
<tr>
<td>Respiratory distress (dyspnea, tachypnea, cyanosis, hypoxemia, hypercarbia)</td>
</tr>
<tr>
<td>Depressed level of consciousness (GCS ≤ 8)</td>
</tr>
<tr>
<td><strong>Urgent indications</strong></td>
</tr>
<tr>
<td>Hypotension or cardiovascular instability</td>
</tr>
<tr>
<td>Penetrating neck injury with airway compromise</td>
</tr>
<tr>
<td>Chest wall injury or disturbance that impairs ventilation despite tube thoracostomy</td>
</tr>
<tr>
<td>Risk of aspiration because of bleeding in the oropharynx or airway and vomiting</td>
</tr>
<tr>
<td><strong>Relative indications</strong></td>
</tr>
<tr>
<td>Oromaxillofacial injuries</td>
</tr>
<tr>
<td>Pulmonary contusion</td>
</tr>
<tr>
<td>Need for diagnostic or therapeutic interventions in a patient who is at risk for deterioration</td>
</tr>
<tr>
<td>Potential respiratory failure due to analgesic or sedative requirements</td>
</tr>
</tbody>
</table>


or paralyzing agents are loss of the airway, loss of spontaneous respiratory effort, aspiration of gastric contents, and hypotension or cardiovascular collapse. For these reasons, the ATLS course does not encourage the use of these drugs. However, in skilled hands, rapid-sequence induction with a combination of an inducing agent and a short-acting paralytic agent, is a highly effective method for securing the airway. The use of sedatives alone, without paralytic agents, may have a theoretical advantage, that is, the patient may continue to breathe spontaneously should the attempt at placing the airway prove unsuccessful. However, this theoretical advantage has not been proved. In fact, in acute care airway situations, complications were greater in number and severity for the nonparalyzed patients compared with standard rapid-sequence induction with a paralytic agent and included aspiration, airway trauma, and death. Intubation is carried out after preoxygenation and is performed under direct vision during direct laryngoscopy. Successful placement of the endotracheal tube is confirmed by visualization of the tube between the vocal cords as it is placed, detection of exhaled CO₂ using a disposable CO₂ detector, and auscultation over the epigastrium and chest.

A number of alternative techniques are available to establish a secure airway in patients who fail orotracheal intubation (such as nasotracheal intubation, laryngeal mask airway, combi-tube, bronchoscopic intubation, “blind” tactile intubation, the “lighted-stylet,” needle cricothyroidotomy and jet ventilation, and retrograde airway placement). However, these methods are heavily dependent on highly trained individuals performing difficult airway techniques and may not be possible with significant blood or secretions in the airway (e.g., bronchoscopic intubation), and the instrumentation may not be available in the emergent situation. Therefore, the surgical cricothyroidotomy is the preferred backup method for acute care surgical airway treatment. This is accomplished by stabilizing the thyroid cartilage with the nondominant hand while making a vertical or horizontal incision over the cricothyroid space, which is often easily palpable. If not palpable, a vertical incision in the approximate area is made and can be extended cephalad or caudally if needed. Palpation confirms the location of the cricothyroid membrane, and a transverse incision is made in this membrane. The back end of the scalpel or a hemostat clamp can be used to dilate the cricothyroidotomy, and an appropriately sized standard endotracheal tube (or tracheostomy tube if available) can be inserted and secured in place. Emergent tracheostomy is not favored because of the greater difficulty associated with this procedure when performed emergently outside of the operating room, requiring greater technical skills and therefore more prone to failure than cricothyroidotomy. However, tracheostomy may be necessary for patients with tracheolaryngeal trauma, as this injury may preclude safe cricothyroidotomy.

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In the primary survey, a number of life-threatening conditions should be sought and corrected immediately upon detection (Table 1.3). Of these, tension pneumothorax, flail chest, massive hemothorax, and open pneumothorax are identified on physical examination, without the need or delay to obtain chest radiography, and should be treated immediately. The initial relief of a tension pneumothorax can be accomplished rapidly by inserting a 14- or 16-gauge needle into the second intercostal space in the midclavicular line. Insertion of a thoracostomy tube into the fourth or fifth intercostal space should then follow. A flail chest results from the fracture of three or more ribs in at least two places. This results in a segment of the chest wall that moves paradoxically with respiration. More important from a physiologic standpoint is the underlying pulmonary contusion, which can lead to significant hypoxic respiratory failure. The pulmonary contusion may require intubation and mechanical ventilation if severe or if the patient has labored respirations or respiratory compromise. Patient mortality more than doubles when pulmonary contusion and flail chest are combined compared with either injury alone. However, more than half of these deaths are directly attributed to central nervous system injuries, with another third caused by massive hemorrhage, demonstrating that these patients often have significant associated injuries.

For patients with major chest wall injuries, adequate analgesia can often best be accomplished with the placement of a thoracic epidural catheter for the continuous infusion of opioids and/or regional anesthetics. Thoracic epidural anesthesia has been shown to be superior to intravenous administration of opioids via patient-controlled analgesia devices. Pain control is critical in

| Table 1.3. The “deadly dozen” lethal and potentially lethal thoracic and airway injuries in trauma patients that should be detected and treated in the primary and secondary surveys. |
|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|
| **Lethal six**  | Airway obstruction | Tension pneumothorax | Cardiac tamponade | Open pneumothorax | Massive hemothorax | Flail chest | **Hidden six**  | Thoracic aorta disruption | Tracheobronchial injury | Blunt cardiac injury | Diaphragmatic injury | Esophageal injury | Pulmonary contusion |

Source: Data from American College of Surgeons Committee.1
the management of chest wall injuries. With inadequate pain control, hypoventilation and splinting may lead to atelectasis or pneumonia and worsen the alveolar hypoventilation and intrapulmonary shunt, resulting in hypoxia and hypercarbia. The use of continuous epidural analgesia is associated with significant improvement in vital capacity and maximum inspiratory pressure in these patients.\textsuperscript{18}

Circulation

Assessment of circulation is done by palpation of pulses and checking skin color, temperature, capillary refill, and mentation. As a general guide, the rate and quality of the pulses can provide important information regarding the adequacy of peripheral circulation and volume status. A strong pulse is associated with adequate cardiac output, whereas a weak, thready pulse often indicates hypovolemia and inadequate cardiac output. Arterial blood pressure is measured. However, a significant drop in blood pressure is a late finding in hemorrhagic shock and may require a blood loss of >30% of total blood volume to manifest (Table 1.4). Thus, a patient with a normal blood pressure measurement may be hypovolemic with ongoing hypoperfusion. On the other hand, the hypotensive patient has compensated physiologically. In trauma patients, a single systolic blood pressure less than 90 mm Hg has an associated mortality rate of 25%. Narrowing of the pulse pressure and mild tachycardia may be the first signs of hypovolemia and may require blood loss of 15% to 30% of total blood volume to become apparent. Normal mentation implies adequate cerebral perfusion, while diminished level of consciousness in the presence of tachycardia and/or hypotension may be associated with shock or hypoxia, irrespective of central nervous system injury. In patients with significant head injuries, secondary brain injury occurs with hypoxia and hypotension, and these two abnormalities need to be aggressively corrected. Morbidity and mortality rates are doubled for patients with traumatic brain injury who develop hypotension and nearly triple if the combination of hypotension and hypoxia occurs.\textsuperscript{22}

Intravenous access should be established immediately in all patients in shock. This is most efficiently accomplished by the insertion of two large-bore (14 or 16 gauge) peripheral lines in the antecubital fossae. Occasionally, percutaneous central venous access or venous cut-downs at the saphenous vein at the ankle or groin will be necessary, although these procedures are more time consuming and require technical skill and therefore are not preferred when peripheral veins are accessible. The choice of intravenous catheter will determine the rapidity with which fluids or blood products can be administered to the patient. As determined by the law of Poiseuille, flow of a fluid through a catheter and intravenous tubing is proportional to the pressure gradient across the catheter, the fourth power of the catheter radius, and inversely proportional to the length of the catheter and the viscosity of the fluid. For this reason, wide catheters and tubing with short lengths will have the advantage of providing the best intravenous access and permit the most rapid delivery of fluids.\textsuperscript{23}

If the trauma patient has signs of hypovolemia or shock, hemorrhage must be immediately identified and controlled. The possible sites of blood loss in the trauma patient include thorax, abdomen, pelvis, retroperitoneum, external hemorrhage, and long bone fractures. Physical examination, plain radiography, focused abdominal sonography for trauma (FAST), and diagnostic peritoneal lavage are the mainstay diagnostic maneuvers. Empiric placement of thoracostomy tubes is often the most efficient diagnostic and therapeutic maneuver for hypotensive patients with thoracic injuries. If this search for bleeding is unrevealing, other causes of shock to consider are tension pneumothorax, cardiac tamponade, high spinal cord injury (neurogenic shock), and severe blunt myocardial injury (rare).

<table>
<thead>
<tr>
<th>Blood loss (mL)</th>
<th>Class I</th>
<th>Class II</th>
<th>Class III</th>
<th>Class IV</th>
</tr>
</thead>
<tbody>
<tr>
<td>Blood loss (% blood volume)</td>
<td>Up to 750</td>
<td>750–1,500</td>
<td>1,500–2,000</td>
<td>&gt;2,000</td>
</tr>
<tr>
<td>Pulse rate</td>
<td>&lt;100</td>
<td>&gt;100</td>
<td>&gt;120</td>
<td>&gt;140</td>
</tr>
<tr>
<td>Blood pressure</td>
<td>Normal</td>
<td>Normal</td>
<td>Decreased</td>
<td>Decreased</td>
</tr>
<tr>
<td>Pulse pressure</td>
<td>Normal or increased</td>
<td>Decreased</td>
<td>Decreased</td>
<td>Decreased</td>
</tr>
<tr>
<td>Respiratory rate</td>
<td>14–20</td>
<td>20–30</td>
<td>30–40</td>
<td>&gt;35</td>
</tr>
<tr>
<td>Urine output (mL/hr)</td>
<td>&gt;30</td>
<td>20–30</td>
<td>5–15</td>
<td>Negligible</td>
</tr>
<tr>
<td>Mental status</td>
<td>Slightly anxious</td>
<td>Mildly anxious</td>
<td>Anxious and confused</td>
<td>Confused, lethargic</td>
</tr>
<tr>
<td>Fluid replacement</td>
<td>Crystalloid</td>
<td>Crystalloid</td>
<td>Crystalloid and blood</td>
<td>Crystalloid and blood</td>
</tr>
</tbody>
</table>

Fluid Resuscitation

Restoration of normal circulation implies prevention or reversal of shock. Shock is defined as the inadequate delivery of oxygen and other metabolic substrates necessary for normal function and survival of cells and tissues. It is important to realize that significant cellular hypoperfusion and death can occur despite normal arterial blood pressure. Equating shock with hypotension and cardiovascular collapse is a gross oversimplification that may result in undue patient morbidity. The optimal type, amount, and timing of fluid administration during the resuscitation of injured patients in hemorrhagic hypovolemic shock remain a subject of intense investigation and debate. Understand that the primary goal in management of active hemorrhage, whether trauma or non-trauma, is to stop the bleeding. With truncal hemorrhage that results in hypotension, these patients need rapid control of bleeding in the operating room: operating room resuscitation.

For patients with hemorrhagic shock in the prehospital setting, aggressive volume infusion in an attempt to normalize blood pressure may be harmful. Until surgical control of hemorrhage has been achieved, aggressive infusion of fluids may actually disrupt hemostatic clots and cause hemodilution and vasodilation, and it has been shown to worsen outcomes in animal models of hemorrhagic shock. In a prospective randomized trial of patients with penetrating torso trauma, patients received either delayed fluid resuscitation upon arrival to the operating room or standard resuscitation by the paramedics. Although a number of technical limitations of this study exist, the trial demonstrated that delayed fluid administration was associated with lower patient mortality. However, a review of the diverse literature on this topic was unable to demonstrate a survival advantage or disadvantage to early or larger volume of intravenous fluid resuscitation in uncontrolled hemorrhage. The literature on this topic is difficult to analyze as a whole because of the inconsistent methodologies employed in the different studies.

Overly aggressive resuscitation may also have other deleterious effects. A study of supranormal resuscitation in severely injured trauma patients with >2L blood loss targeted resuscitation to a supraphysiological cardiac index (≥4.52 L/min/m²) and oxygen delivery (≥500 mL/min/m²). In this small study, the ability to attain these supranormal hemodynamic values was associated with improved survival and decreased morbidity rates. However, this effect was more a reflection of the patients’ abilities to achieve these parameters in this subset rather than benefits of therapy. Subsequent studies of supranormal resuscitation have not shown benefit. In fact may demonstrate a detrimental effect of the supranormal resuscitation strategy. For trauma patients, resuscitation using oxygen delivery ≥500mL/min/m² was indistinguishable from oxygen delivery at ≥600mL/min/m². Less volume loading was required to attain and maintain oxygen delivery at ≥500mL/min/m² than at 600mL/min/m² using a computerized algorithm to standardize resuscitation during the first 24 hours. Supranormal resuscitation, compared with standard resuscitation, is associated with more lactated Ringer’s infusion, decreased intestinal perfusion, and increased incidence of abdominal compartment syndrome, multiple organ failure, and death in trauma patients.

It is clear that both extremes—no fluid versus massive resuscitation—should be avoided as they are detrimental to patient outcome. What is also clear is that surgical control of hemorrhage should be considered part of the initial resuscitation of patients in hemorrhagic shock. Attempts at resuscitation in this situation will be futile and perhaps detrimental, as definitive control of bleeding will be delayed.

Much has been written with regard to the choice of fluid used for the resuscitation of patients in shock. Clearly, most critically ill patients will require volume expansion at some point with the goal of restoring intravascular volume and preserving tissue perfusion and oxygenation. Options include isotonic crystalloids, hypertonic fluids, natural and synthetic colloids, blood products, and other novel solutions. At present, the first-line fluid of choice for the resuscitation of patients in shock remains isotonic crystalloids, such as lactated Ringer’s or normal saline solutions. These fluids have a long history of proven effectiveness and are inexpensive, readily available, and easy to preserve. The theoretical advantages of colloids such as albumin solutions include the possibility that they will provide more rapid restoration of intravascular volume with a smaller volume of infused fluid than crystalloids. Colloids may also be associated with less tissue and lung edema and may preserve plasma albumin levels. The potential disadvantages of colloids include their cost and the fact that, in the leaky capillary syndrome seen in many critically ill patients, albumin infusion may not preserve the intravascular oncotic pressure but rather leak into the extravascular space. Hypertonic saline solution combines some of the advantages of crystalloids and colloids. Hypertonic saline may cause less peripheral edema than isotonic fluids, as it draws intracellular fluid into the vascular space. It also may have fewer detrimental effects on immune function. Several studies have examined the role of hypertonic saline compared with isotonic saline in trauma patients, and no clear difference in outcomes could be shown. However, some benefit may result from infusion of hypertonic saline in patients with penetrating injuries or those with combined traumatic brain injury and shock.

Several studies have attempted to answer the question as to the benefits of colloids and crystalloid solutions.
One large meta-analysis of the use of albumin versus crystalloids showed a trend toward an increased mortality rate for a variety of critically ill patients who received albumin. However, in other large meta-analyses of the literature comparing albumin solutions with crystalloids for a wide variety of surgical and nonsurgical indications, no difference in mortality rate was detected based on the choices of resuscitation fluid. These meta-analyses include heterogeneous populations of patients and studies of differing designs, confounding the interpretation of the results. At this time, no strong recommendation can be made to support the use of colloids over crystalloids for patients in shock.

The availability of newer colloid solutions, such as hydroxethyl starch (HES) have renewed this debate. Synthetic starch solutions HES have been used clinically to restore intravascular volume in patients with shock. Several HES solutions are available clinically that differ in the molecular mass fractions of HES and in the composition of the electrolyte solution. The studies that have analyzed the use of HES as a resuscitation fluid are encouraging. In a canine model of hemorrhagic shock, fluid resuscitation during uncontrolled bleeding resulted in higher oxygen delivery and lower systemic lactate concentrations when HES (6%) was used compared with lactated Ringer’s solution during resuscitation.45

There are concerns regarding the development of coagulopathy with the infusion of HES, because it is known to inhibit platelet function. However, fluid resuscitation with low-molecular-weight HES may reduce the risk of bleeding associated with HES of higher molecular weight and degree of substitution.46 Also, a dilutional effect on coagulation function independent of the type of resuscitation fluid employed has been observed.47 Furthermore, colloids with a more physiologically balanced electrolyte formulation may result in less metabolic acidosis and alteration of intestinal perfusion. In a prospective, randomized, blinded trial with elderly surgical patients, the use of balanced electrolyte HES helped prevent the development of hyperchloremic metabolic acidosis and provided better gastric mucosal perfusion than saline-based HES.48 Clearly, not all resuscitation fluids are equivalent, and patient outcomes will depend on the timing and on the amount and type of fluid employed.

Alternative crystalloid resuscitation fluids are being evaluated. One promising option is Ringer’s ethyl pyruvate solution (REPS), which has been assessed in a number of studies using animal models of mesenteric ischemia/reperfusion injury, hemorrhagic shock, and acute endotoxemia. In these animal models, infusion of REPS, when compared with Ringer’s lactate solution, was shown to improve survival and decrease expression of proinflammatory cytokines. Ringer’s ethyl pyruvate solution merits further evaluation for the resuscitation of patients with hemorrhagic shock, sepsis, and trauma.

There remains a need for well-designed clinical trials to determine whether colloids or crystalloids are better for the resuscitation of trauma patients. Because of many limitations, the existing meta-analyses must be interpreted with caution. However, with this in mind, a meta-analysis of this literature regarding humans suggests that trauma patients should continue to be initially resuscitated with crystalloids at this time.

Transfusion

The use of blood products in the care of critically ill and injured patients has saved many lives. However, evidence-based practices are evolving regarding the use of blood products. A multicenter, randomized clinical trial has clearly shown that, for critically ill patients in the intensive care unit (predominantly nontrauma patients), a restrictive strategy that employs a hemoglobin transfusion trigger of 7 g/dL is as at least as effective and may be superior to a liberal transfusion threshold of 10 g/dL. In fact, the 30-day mortality rate was lower for the subgroup of patients with Acute Physiology and Chronic Health Evaluation (APACHE) II score of ≤20 who were randomized to the restrictive transfusion strategy. Patients who were deemed to have ongoing bleeding were excluded from this study. The same investigators published a subsequent study involving patients with known cardiovascular disease that showed similar 30- and 60-day survival rates for the restrictive and liberal transfusion strategies, with the exception of patients with acute myocardial infarction or unstable angina. For the patients with acute coronary syndromes (not simply a history of coronary artery disease), outcomes with a hemoglobin transfusion threshold of 10 g/dL were improved. For the trauma population, red blood cell transfusion has been shown to be a predictor of mortality, independent of severity of shock as determined by arterial base deficit, serum lactate level, shock index, and degree of anemia. In addition, there is a dose-dependent correlation between transfusions of packed red blood cells and the development of infection in trauma patients. Multivariate analyses show that transfusion of blood within 48 hours of hospital admission is an independent risk factor for the development of nosocomial infections. For other critically ill patients, a similar association between blood transfusion dose and nosocomial infections has been demonstrated. The administration of blood transfusions is also an independent risk factor for the
development of multiorgan failure in trauma patients independent of other indices of shock. On the other hand, empiric blood transfusions should be administered to trauma patients in shock who fail to respond to initial resuscitation with crystalloids. As mentioned earlier, this patient group often requires prompt operative control of hemorrhage.

Because of these and other known detrimental effects associated with blood transfusion, as well as the limitations related to cost and availability (e.g., in the battlefield or prehospital setting), hemoglobin-based oxygen carriers (HBOCs) are being evaluated as an alternative to blood transfusion. While several varieties of HBOCs have been developed, the polyhemoglobin is the most promising at this time; these include human recombinant polymerized hemoglobin and bovine hemoglobin glutamer 250. The HBOCs have been shown to be effective and safe for the resuscitation of shock in animal models and to improve survival rates better than resuscitation with crystalloids or HES solutions. Small clinical studies show promise for the use of HBOCs for surgical and trauma patients. There are currently phase III clinical trials in progress that will attempt to answer this question for human patients, and the HBOCs may become important in the early resuscitation of patients with anemia and shock.

Other Resuscitation Efforts

Emergency department resuscitative thoracotomy, surgical exploration for control of active hemorrhage (e.g., repair of ruptured abdominal aortic aneurysm, splenectomy for active hemorrhage from splenic injury), stabilization of pelvic fractures, and control of external bleeding should all be considered part of the stabilization of circulation phase of the primary survey of hemodynamically abnormal and unstable patients. The best results for emergency department resuscitative thoracotomy are obtained for patients with penetrating injuries to the thorax, who had obtainable vital signs, and who suffer rapid deterioration in the emergency department, with up to 20% survivorship. Patients with penetrating abdominal injuries had significantly lower survivorship (6.8%), and survivors with blunt thoracic trauma who required emergent thoracotomy were extremely rare (0.5%). For patients with penetrating thoracic injuries who have vital signs at the scene or in the emergency department, survival is much higher than for those who did not have obtainable vital signs. Meanwhile, trauma patients who are pulseless and whose electrical cardiac activity is asystolic or agonal (wide complex heart rate <40 beats/min) can be pronounced dead. Thus, although all these data are understandably retrospective, significant judgment must be exercised in selecting patients for emergency department resuscitative thoracotomy.

Assessment of Resuscitation

The ability to assess clinically relevant parameters of tissue and organ perfusion and to employ this knowledge to improve patient outcomes is the core of critical care medicine. Unfortunately, consensus is lacking regarding the most appropriate parameters to monitor to achieve this goal. Of the highest importance is the integration of physiologic data obtained from monitoring into a coherent treatment plan. Thus, endpoints of resuscitation must be defined.

Classic Physical Examination Findings and Vital Signs

Vital signs, namely, heart rate and blood pressure, can be monitored to formulate conclusions regarding volume status and adequacy of resuscitation. However, changes in blood pressure and heart rate are insensitive for the detection of early hypoperfusion.

Urine Output

Bladder catheterization with an indwelling catheter allows the monitoring of urine output, usually recorded hourly. Over a period of observation, urine output is a gross indicator of renal perfusion. The generally accepted normal urine output is 0.5 mL/g/hr for adults and 1–2 mL/kg/hr for neonates and infants. Oliguria may reflect inadequate renal artery perfusion caused by hypotension, hypovolemia, or low cardiac output state or may be associated with intrinsic renal pathology such as acute tubular necrosis. However, normal urine output does not exclude the possibility of hypoperfusion or impending renal failure. Therefore, the measurement of urinary electrolytes, calculation of the fractional excretion of sodium or urea, urinalysis with examination of sediment, and renal ultrasonography are often employed to elucidate the causes of rising blood urea nitrogen (BUN) and serum creatinine levels and the development of oliguria.

Bladder Pressure (Abdominal Compartment Syndrome)

The triad of oliguria, elevated peak airway pressures, and elevated intraabdominal pressure is termed the abdominal compartment syndrome (ACS). This syndrome was first described in patients after repair of ruptured abdominal aortic aneurysms, and it is associated with interstitial edema of the abdominal organs, resulting in elevated intraabdominal pressure, which causes in decreased renal perfusion and oliguria as well as hypoperfusion to other intraabdominal viscera. Other common etiologies of ACS include blunt and penetrating abdominal trauma, often
with liver, vascular, splenic injuries, or pelvic fractures, especially if abdominal packing is performed. Severe burns, massive resuscitation, or ischemia/reperfusion of the abdominal viscera may also produce intra-abdominal hypertension.

Although the diagnosis of ACS is a clinical one, based on the presence of hypotension, oliguria, increased airway pressures, and abdominal distension, measuring intra-abdominal pressure may assist in making the diagnosis. Ideally, a catheter inserted into the peritoneal cavity could measure intraabdominal pressure to substantiate the diagnosis. In practice, transurethral bladder pressure measurement reflects intraabdominal pressure and is most often used to confirm the presence of intra-abdominal hypertension (IAH). After instilling 50 to 100 mL of sterile saline into the bladder via a Foley catheter, the tubing is connected to a transducing system to measure bladder pressure. A bladder pressure of 20 to 25 cm H2O in the appropriate clinic setting suggests IAH. Treatment consists primarily of abdominal decompression, most effectively accomplished by laparotomy, leaving the abdomen open. The mortality rate associated with ACS is high, reaching 60% to 70%, reflecting delayed diagnosis and the underlying pathophysiology in these critically ill patients. Thus, prevention is critical. For patients with a high likelihood of development of abdominal compartment syndrome, a temporary abdominal closure with a plastic bag, vacuum pack, or sterile intravenous bag is prudent.

Ventricular Preload

Invasive measurements of ventricular preload such as right atrial and pulmonary artery occlusion pressures and their changes in response to volume loading are inadequate predictors of intravascular volume status and cardiac output. Also, while cerebral and myocardial perfusion may be preserved in compensated shock, mesenteric perfusion may be seriously compromised. Splanchnic hypoperfusion is associated with functional and structural changes in the intestinal mucosa, resulting in increased mucosal permeability and the translocation of bacteria and bacterial products. Increased intestinal mucosal permeability has been associated with the development of multiorgan dysfunction in septic human patients. The rapid detection and correction of tissue hypoperfusion may limit organ dysfunction, reduce complications, and improve patient outcome. It is intuitive that the earlier tissue hypoperfusion is detected and corrected the greater the likelihood that outcome may be improved. This has now been shown by Rivers and colleagues, who reported a 32% relative reduction in the 28-day mortality rate for patients with severe sepsis who received early aggressive volume resuscitation in the emergency department. In this study, the central venous oxygen saturation (ScvO2) was used as the endpoint of resuscitation in the intervention group, whereas in the control group treatment was guided by standard clinical endpoints, including the central venous pressure.

Lactate Level

Hyperlactacidemia is thought to correlate with tissue hypoxia and anaerobic glycolysis, often in the setting of normal blood pressure and cardiac output. Lactate may be generated by well-oxygenated tissues. In injured patients, increased aerobic glycolysis in skeletal muscle secondary to epinephrine-stimulated Na+,K+-ATPase activity may increase blood lactate levels. This may explain why hyperlactacidemia often does not correlate with traditional indicators of perfusion and fails to clear with increased oxygen delivery. Continued attempts at resuscitation based on elevated blood lactate level may lead to unnecessary use of blood transfusion and inotropic agents in an effort to increase oxygen delivery and lactate clearance.

Base Deficit

The base deficit (BD) is a commonly used endpoint of trauma resuscitation. The BD is of prognostic value and correlates with mortality rate and with the development of organ dysfunction in a number of retrospective studies. In a retrospective review of nearly 3,000 patients admitted to a level I trauma center, an admission BD greater than 6 predicted likelihood for early transfusion, prolonged intensive care unit (ICU) and hospital length of stays, and increased risk for shock-related complications. The risks of developing adult respiratory distress syndrome, renal failure, coagulopathy, multiorgan failure, and death rose significantly with increasingly severe BD. The use of an injury severity score (ISS) and the BD may identify patients who require more invasive monitoring and aggressive resuscitation.

In a large, prospective, multicenter, observational study of over 2,000 multitrauma patients, the arterial BD on hospital and intensive care unit (ICU) admission was an important predictor of hemodynamic instability, transfusion requirement, metabolic and coagulation abnormalities, and mortality. In this study, mortality also increased significantly with a worsening of BD from hospital to ICU admission. Therefore, an elevated BD may help guide an early and aggressive resuscitation for the multi-trauma patient. Trend and response to therapy with correction of the BD are more important than a single determination of BD.

The use of the BD is based on the principle that tissue hypoperfusion will result in the development of an “oxygen debt” and metabolic acidosis. However, tissue hypoperfusion may occur without a significant change in
the BD. Furthermore, as it requires time for regeneration of bicarbonate by the liver and kidney, a delay can be expected between the correction of tissue perfusion and normalization of the BD. This was demonstrated in a murine hemorrhagic shock model that showed that the BD responded slowly to changes in intravascular volume and that there was a significant increase in the BD only when the mean arterial blood pressure fell by greater than 50%. In contrast, this study demonstrated that changes in the esophageal CO₂ gap correlated well with changes in intravascular volume status. Similar findings have been reported by other investigators. In patients with penetrating trauma, the sublingual CO₂ measurements correlate with the amount of blood loss. Similarly, the gastric intramucosal pH has been reported to correlate with the severity of injury and hypoperfusion. The BD may be a less sensitive indicator of the degree of intravascular volume deficit following hemorrhage, and it responds slowly to volume resuscitation. Esophageal or sublingual capnometry, however, may provide real-time assessment of hypoperfusion and the adequacy of volume resuscitation. This technology is simple, less invasive than pulmonary artery catheterization, and ideally suited for use in the trauma bay and ICU. Esophageal or sublingual capnography may prove to be a useful endpoint for the resuscitation of trauma patients in the future.

The Triad of Death: Hypothermia, Acidosis, and Coagulopathy

Postinjury life-threatening coagulopathy in the seriously injured person requiring massive transfusion is predicted by persistent hypothermia and progressive metabolic acidosis. The independent risk factors for the development of life-threatening coagulopathy in multitrauma patients receiving massive transfusion are acidosis (pH < 7.10), hypothermia (core temperature <34°C), ISS > 25, and systolic blood pressure <70 mm Hg. The most important and effective strategy is to prevent the development of this triad: active correction of hypothermia, hypovolemia, ongoing hemorrhage and acidosis. Admission hypothermia, defined as temperature <36°C, is present in as many as two-thirds of patients admitted to level I trauma centers and therefore must be actively corrected.

Damage control procedures involve limited surgery for the immediate correction of ongoing hemorrhage and contamination, followed by resuscitation in the intensive care unit. During this ICU phase of resuscitation, physiologic abnormalities are corrected. Aggressive resuscitation of the patient occurs, with active rewarming of hypothermic patients, correction of acidosis and hypoperfusion with infusion of fluids and red blood cells, and correction of coagulopathy with rewarming and infusion of blood products. After correction of the physiologic abnormalities, subsequent reoperation can be performed for definitive correction of anatomic abnormalities.

In addition to the infusion of fresh-frozen plasma and platelets, other approaches available to correct coagulopathy include the infusion of specific coagulation factors. The most promising is recombinant activated factor VII (rFVIIa). Recombinant activated factor VII reduces blood loss in hypothermic and coagulopathic swine with severe hepatic injuries when used as an adjunct to packing. Recombinant activated factor VII has been shown in small human series to be effective in treating bleeding associated with coagulopathy in obstetrical patients and trauma patients with multifactorial coagulopathy. This raises the possibility of therapeutic use of rFVIIa for patients with coagulopathy and ongoing blood loss.

Damage control surgery has emerged as the preferred management strategy for trauma patients with abdominal injuries complicated by hypothermia, coagulopathy, and acidosis. It appears that the concept of damage-control surgery and correction of hypothermia and coagulopathy have a positive impact on patient survival for those who have had massive blood transfusion or who are in the early phases of the downward spiral of hypothermia, coagulopathy, and acidosis. This approach can be used for both critically ill trauma and nontrauma patients.

Shock

As stated earlier, shock is defined as inadequate delivery of oxygen and nutrients to cells and tissues. It should be noted that significant tissue hypoperfusion can occur despite normal arterial blood pressure; the definition of shock is independent of this parameter. However, the presence of hypotension implies more severe physiologic insult and degree of decompensation. In 1934, Blalock proposed four categories of shock: hypovolemic, vasogenic, cardiogenic, and neurologic. Two additional categories of shock have been described: obstructive and traumatic. From a clinical perspective, a simple differential diagnosis can often be formulated for hypotensive patients in shock based on the presence or absence of loss of vascular resistance, as evidenced by the pulse pressure (Table 1.5).

Hypovolemic and Hemorrhagic Shock

Hypovolemia in the presence of hemorrhage is the most common cause of shock in the trauma patient and results from the loss of circulating blood volume from either hemorrhage or loss of plasma fluid. Acute loss of circu-