CHAPTER 18

MANAGEMENT OF ACUTE TRAUMA

R. Shayn Martin and J. Wayne Meredith

OVERVIEW AND HISTORY

Treatment of the injured patient has been a predominant mission of the surgeon since the origin of medical care. Few other surgical disciplines incorporate such a wide range of skills as those required by the surgeon who is managing severe injury. The treatment of injuries predates recorded history, with evidence of neurosurgical procedures discovered from approximately 10,000 BC. Although the science of improving how injuries are managed progresses continuously, it has been during wartime that many of the greatest advancements were achieved because of the high burden of injury during these relatively short periods. Box 18-1 lists some major contributions to trauma care that were developed during wartime. Common themes include improvements in wound management, resuscitation, and rapid access to care. Recently, the research of trauma care in the military theater has been formalized, which has allowed even greater advances to be achieved.

The organization of trauma care has also evolved over the last century as the field matured into a distinct surgical specialty. After the formation of the American College of Surgeons (ACS) in 1913, the leadership of the organization appointed a committee to report on the management of fractures. Created in 1922, the Committee on Fractures evolved to become the Committee on Trauma (COT) in 1949 as the need to formally influence formally how trauma care is provided became evident. Beginning with the publication of the Early Care of the Injured, the COT has been instrumental in advancing trauma care throughout the world via initiatives such as the Advanced Trauma Life Support (ATLS) course, verification of trauma centers, and development of trauma systems that improve access to care. The COT has defined appropriate structure, process, and outcomes, as outlined in Resources for the Optimal Care of the Injured Patient, which is used extensively by trauma centers worldwide. The COT also has developed the National Trauma Data Bank (NTDB), which is the largest database of trauma patients in existence, currently including over 3 million patients from 567 trauma centers. Just as the COT was commissioned by the ACS at the national level, it has also formed individual committees on trauma at the state level that work under the direction of the national committee. This structure has proven to be powerful by allowing many of the endeavors that advance the care of the injured patient to occur at the state level, because leadership infrastructure and politics differ regionally. Activities of the state committees frequently include trauma system development with the creation of triage documents, maximizing the use of prehospital and hospital resources, injury prevention initiatives, maintenance of statewide trauma registries, and advancement of performance improvement efforts. Frequently, a major part of this work is the ongoing pursuit of reliable funding mechanisms to pay for the improvement in trauma care throughout the state. Within the infrastructure of the national COT, states are also grouped into regions, which allows for the sharing of information pertaining to successful statewide initiatives and the discussion of issues involving bordering states.

Several other organizations have been formed, with the primary goal of promoting the improvement of trauma care. The American Association for the Surgery of Trauma (AAST) originated in 1938 and is the largest of all trauma professional organizations. The AAST conducts an annual scientific conference in September that allows for the sharing of information and promotion of the science of injury management. The AAST has also been the lead organization in the creation of the new training paradigm called acute care surgery, which includes advanced education in trauma, surgical critical care, and emergency general surgery. Several centers are now providing training in acute care surgery, with many others working to develop programs. The Eastern Association for the Surgery of Trauma (EAST) and the Western Trauma Association (WTA) are also prominent academic organizations that promote the exchange of scientific advances in trauma care. Both these groups have active multi-institutional trial committees and have been instrumental in the development of practice management guidelines. Injury prevention and trauma system development has been greatly advanced by the American Trauma Society (ATS). The ATS was founded in 1968 and has been a leader at the national level by advocating for the injured patient and promoting...
think of the goal of a trauma system as getting the right patient to the right place at the right time. The establishment of trauma systems is a relatively new development, with Illinois and Maryland first creating a system for addressing injuries in the early 1970s. Congress recognized that are better able to respond to injury have developed an organized approach to providing all the elements that maximize the potential for meaningful recovery, called a trauma system. Trauma systems encompass the entire care continuum, starting at the time of the injury, with a patient’s access to care, through the rehabilitation process. At the most basic level, one might think of the goal of a trauma system as getting the right patient to the right place at the right time.

Historically, the provision of trauma care was centered around the large academic hospitals that provided the vast majority of injury management. Prehospital efforts focused on getting all patients to the trauma center, regardless of the degree of injury. Although initially found to be beneficial to those patients who were transported to the trauma center, this exclusive type of system failed to address the needs of patients who were geographically distant from the trauma center. Furthermore, this type of system did not capitalize on the resources that could be provided in non–trauma center hospitals. The solution was the development of inclusive trauma systems designed to address the needs of all injured patients, regardless of their severity of injury or geographic location. Inclusive trauma systems capitalize on the resources of all hospitals from critical access facilities to the large levels I and II trauma centers. Guided by predeveloped triage protocols, injured patients are transported to facilities that can provide the level of care necessary to manage injuries of varying severity. At times, this requires transferring patients from smaller hospitals to larger hospitals or trauma centers. Box 18-2 lists the common components of an inclusive trauma system that must be coordinated to maximize the efficiency of getting the injured patient to the care location that he or she needs most. The benefits of this approach include the efficient use of all available resources, reduction in potentially overwhelming trauma centers with patients of lower acuity, and allowing most patients to receive appropriate care within their own community. Finally, it is essential to recognize that legislation plays a large role in the establishment and maintenance of trauma systems. Only through ongoing legislative support can the systematic approach to trauma care grow to eliminate the possibility of a patient lacking access to appropriate, high-quality care for his or her injuries.

The establishment of trauma systems is a relatively new development, with Illinois and Maryland first creating a system for addressing injuries in the early 1970s. Congress recognized trauma-related legislation. Finally, the care of the injured patient is a multidisciplinary process, which has accordingly driven the formation of organizations in many other fields that play a role in trauma care. The Orthopedic Trauma Association (OTA), American Association of Neurological Surgeons (AANS), and Society of Trauma Nurses (STN) represent three organizations whose members are part of the multidisciplinary team dedicated to improving the care of the injured patient.

**TRAUMA SYSTEMS**

Interstate 40 runs 2550 miles from Wilmington, on the coast of North Carolina, to Barstow, California. If a car crash were to occur along I-40, the unfortunate reality is that the outcome after a given severity of injury is dependent on where along the highway the crash occurs. This illogical finding is a reflection of the variability in a patient’s access to care that is provided throughout the United States and the rest of the world. Regions
the need for a coordinated approach to the management of injuries and passed the Trauma Care Systems Planning and Development Act of 1990, which formally addressed the need for trauma systems. The development of trauma systems was further advanced with the release of the Model Trauma Care System Plan by the Health Resources and Services Administration (HRSA). Originally released in 1992 and then revised in 2006, the newly titled Model Trauma System Planning and Evaluation document applied a public health approach to trauma and provided valuable direction for developing and evaluating trauma systems. This public health approach identified trauma as a disease, the impact of which can be prevented or decreased by applying already established systems that address other health-related issues, such as infectious diseases. Finally, the American College of Surgeons’ COT established the Trauma Systems Consultation Program in 1996 to guide states or regions in the process of developing a systematic approach to trauma care.

The impact of trauma systems on the care people receive after injury has been well studied and provides support for ongoing societal investment in this approach. In 2000, Nathens and colleagues published their evaluation of more than 400,000 patients treated over a 17-year period. During the study period, trauma systems were established and developed in many of the regions evaluated. After correcting for all identifiable injury prevention and management improvements, the development of a trauma system over an approximately 10-year period resulted in a reduction in mortality by 8%. Several others have also reported this effect, demonstrating an improvement in outcomes in areas that establish a systematic approach to injury management. Most recently, the National Study on Costs and Outcomes of Trauma (NSCOT) was performed to evaluate variations in injury care and outcomes between trauma centers and non–trauma centers. Supported by the National Center for Injury Prevention and Control of the Centers for Disease Control and Prevention (CDC), NSCOT represents one of the largest epidemiologic studies ever to evaluate trauma care; it included more than 5000 patients from 69 hospitals. NSCOT established that injured patients treated at a trauma center experienced improved outcomes over those treated at non–trauma centers. After correction for injury severity, care at a trauma center was associated with a reduction in mortality of 20% in-hospital and 25% at 1 year.

Trauma system development and maintenance benefit from the contributions of physicians of all different types who work at locations ranging from the smallest rural hospital to the largest academic medical center. Even in areas in which definitive trauma care is not provided, health care personnel play a vital role by establishing triage plans and providing initial stabilization and patient transfer. Highly functional trauma systems require the involvement of local leaders from hospitals, government, and prehospital agencies to develop the regional trauma system and work with surrounding trauma centers to ensure appropriate care for patients with all levels of injury severity.

### INJURY SCORING

To characterize injuries accurately for the purposes of clinical management, benchmarking, and research, several injury scoring systems have been developed. These typically are based on the anatomy of the injury or the resulting physiology, with several types systems created and evaluated over the last 40 years. One of the first anatomy-based scoring systems was the Abbreviated Injury Scale (AIS), initially published in 1971. The AIS characterizes injuries using a six-digit taxonomy that describes the body region, type of anatomic structure, and specific anatomic detail of the injury. As seen in Table 18-1, the first digit of the AIS score defines the affected body region, allowing clinicians and researchers to identify the location of described injuries quickly. The AIS also assigns a severity code to the injury as a seventh digit, which ranges between 1 (minimal severity) and 6 (presumably fatal). The AIS has been updated six times since the original publication and remains one of the most commonly used injury coding systems.

Although the AIS successfully describes individual injuries, it fails to reflect the impact of multiple injuries sustained by the same patient. In 1974, Baker and colleagues’ presented the Injury Severity Score (ISS), calculated by summing the squares of the AIS severity codes for the three most severely injured body regions. Minor injury has been defined as an ISS less than 9, whereas moderate injury is between 9 and 16, serious injury is between 16 and 25, and severe injury is suggested by a score more than 25. The ISS has been used extensively since its development as a way of quantifying the overall injury burden sustained by a given patient. Many other anatomic injury coding systems have since been developed, each with their own merits, although a comprehensive discussion of these exceeds the scope of this chapter. One of the most recent advances in injury coding has been the development of the Organ Injury Scales (OIS) by the American Association for the Surgery of Trauma (AAST), which have been incorporated into the most recent update of the AIS. The OIS provides greater anatomic detail to specific organs that was lacking in the AIS. They also have introduced the concept of injury grades, which provide a standard way of describing organ injury severity and the associated risk of morbidity and mortality. Another attribute of the OIS taxonomy is that the severity suggested by the injury grade has been validated using the NTDB.

Although anatomic scoring methods are more readily used to compare groups of like injuries, physiologic scoring systems may have more real-time clinical value. Physiologic scores provide a better indication of the injured patient’s condition and can therefore be used to make treatment decisions or develop a prognosis. Probably the most commonly used is the Glasgow Coma Scale (GCS), which reflects a patient’s level of consciousness. With scores ranging from 3 to 15, the GCS is composed of a measure of eye opening, verbal response, and motor function. The GCS and more specifically the motor score alone have

<table>
<thead>
<tr>
<th>AIS FIRST DIGIT</th>
<th>BODY REGION</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Head</td>
</tr>
<tr>
<td>2</td>
<td>Face</td>
</tr>
<tr>
<td>3</td>
<td>Neck</td>
</tr>
<tr>
<td>4</td>
<td>Thorax</td>
</tr>
<tr>
<td>5</td>
<td>Abdomen</td>
</tr>
<tr>
<td>6</td>
<td>Spine</td>
</tr>
<tr>
<td>7</td>
<td>Upper extremity</td>
</tr>
<tr>
<td>8</td>
<td>Lower extremity</td>
</tr>
<tr>
<td>9</td>
<td>Unspecified</td>
</tr>
</tbody>
</table>
been found to be reflective of patient outcome after traumatic brain injury. Other examples of physiologic scores commonly used are the Trauma Score (TS) and the Revised Trauma Score (RTS), which are composed of the GCS as well as physiologic variables, such as systolic blood pressure, respiratory rate, and capillary refill time to quantify the injured patient’s condition. The GCS and the RTS are depicted in Tables 18-2 and 18-3. These scores have been of value for research purposes and have been used for making triage decisions with some success.

PREHOSPITAL TRAUMA CARE

Immediately after a patient is injured, the prehospital phase of care begins with the goal of moving a patient to a location capable of providing definitive injury management as quickly as possible. Because of the time-dependent nature of many severe injuries, prehospital personnel play an integral role in the ultimate outcome of the trauma patient. The initial approach to prehospital injury care can be summarized into four priorities:

1. Evaluate the scene.
2. Perform an initial assessment.
3. Make critical interventions and triage-transport decision.
4. Transport the patient.

This list of priorities is intentionally brief because the outcome for each patient depends greatly on how quickly definitive hemorrhage control is obtained. For that reason, only critical interventions should occur prior to initiating transportation to the definitive care facility.

Prehospital providers must begin by evaluating the scene first to ensure his or her safety. The remaining scene assessment should be rapid and completed as the patient is approached. The initial assessment consists of a systematic approach to identify life-threatening conditions immediately that require urgent intervention. This assessment follows the well-known ABC mnemonic, in which airway, breathing, and circulation are sequentially addressed. During this time, an airway is established and assisted ventilation is provided if necessary. Spinal immobilization is provided with a hard collar and long spine board. Assessment and support of circulation includes immediate control of external hemorrhage and initiation of fluid resuscitation.

The success of the prehospital trauma management hinges on immediately making a triage and transport decision. Severely injured patients should be immediately transported to an appropriate hospital for definitive care using the “Load and go” philosophy, with all remaining care provided en route. Valuable prehospital care including a head to toe examination, continuous monitoring, placement of subsequent intravenous access, and environmental control can be provided while the patient is being transported. Although the decision to depart the scene rapidly is often simple, where to go and how to get there can be much more challenging. These decisions should be made well in advance and then implemented in the form of well-outlined protocols and agreements that were developed during trauma system planning endeavors. To guide this process, the COT and the CDC have developed a Field Trauma Decision Scheme, which is included in the updated COT document1 (Fig. 18-1). This systematic approach to triage uses physiologic status, mechanism of injury, and identification of high-risk patients to assist in deciding who might benefit from immediate transfer to a trauma center. Finally, the value of rapidly making a triage and transport decision within minutes of patient arrival and then quickly departing to keep scene times less than 10 minutes cannot be overemphasized.

One of the primary goals of prehospital trauma care is maintaining control of the injured patient’s airway. The gold standard for airway maintenance in severely injured patients remains oral endotracheal intubation, typically using a rapid-sequence technique with spine stabilization. There has been some controversy recently that has questioned whether advanced airway management in the prehospital setting is more harmful than basic airway support with a bag valve mask and basic airway adjuncts. The existing literature has been unable to address this question adequately. For example, Eckstein and colleagues1 have retrospectively evaluated 496 injured patients and found that endotracheal intubation was associated with a greater mortality compared with bag valve mask support. Studies such as these are limited by selection bias and at best can suggest that this

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**Table 18-2 Glasgow Coma Scale**

<table>
<thead>
<tr>
<th>PARAMETER</th>
<th>SCORE</th>
</tr>
</thead>
<tbody>
<tr>
<td>Eye Opening</td>
<td></td>
</tr>
<tr>
<td>Spontaneous</td>
<td>4</td>
</tr>
<tr>
<td>To voice</td>
<td>3</td>
</tr>
<tr>
<td>To pain</td>
<td>2</td>
</tr>
<tr>
<td>None</td>
<td>1</td>
</tr>
<tr>
<td>Verbal Response</td>
<td></td>
</tr>
<tr>
<td>Oriented</td>
<td>5</td>
</tr>
<tr>
<td>Confused</td>
<td>4</td>
</tr>
<tr>
<td>Inappropriate</td>
<td>3</td>
</tr>
<tr>
<td>Incomprehensible</td>
<td>2</td>
</tr>
<tr>
<td>None</td>
<td>1</td>
</tr>
<tr>
<td>Motor Response</td>
<td></td>
</tr>
<tr>
<td>Obey commands</td>
<td>6</td>
</tr>
<tr>
<td>Localizes pain</td>
<td>5</td>
</tr>
<tr>
<td>Withdraws to pain</td>
<td>4</td>
</tr>
<tr>
<td>Flexion</td>
<td>3</td>
</tr>
<tr>
<td>Extension</td>
<td>2</td>
</tr>
<tr>
<td>None</td>
<td>1</td>
</tr>
<tr>
<td><strong>Total Glasgow Coma Score</strong></td>
<td>3-15</td>
</tr>
</tbody>
</table>

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**Table 18-3 Revised Trauma Score**

<table>
<thead>
<tr>
<th>GSC SCORE</th>
<th>SBP (mm Hg)</th>
<th>RR (breaths/min)</th>
<th>CODED VALUE</th>
</tr>
</thead>
<tbody>
<tr>
<td>13-15</td>
<td>&gt;89</td>
<td>10-29</td>
<td>4</td>
</tr>
<tr>
<td>9-12</td>
<td>76-89</td>
<td>&gt;29</td>
<td>3</td>
</tr>
<tr>
<td>6-8</td>
<td>50-75</td>
<td>6-9</td>
<td>2</td>
</tr>
<tr>
<td>4-5</td>
<td>1-49</td>
<td>1-5</td>
<td>1</td>
</tr>
<tr>
<td>3</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td><strong>Total Revised Trauma Score</strong></td>
<td>0-12</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
FIGURE 18-1 Field triage decision scheme created to guide the development of state and local emergency medical services (EMS) triage protocols. The scheme uses four decision steps—physiologic, anatomic, mechanism of injury, special considerations—to guide triage decisions in the local trauma system. (From Committee on Trauma, American College of Surgeons: Resources for the optimal care of the injured patient, ed 5, Chicago, 2006, American College of Surgeons.)
question be studied prospectively. There has also been work specifically in brain-injured patients that argues the converse and thus supports the use of prehospital endotracheal intubation. Finally, it is of value to have several airway rescue techniques and methods available because many have been found to facilitate intubation or provide a bridge to a definitive airway. Two examples that are well studied are the gum elastic bougie and blind insertion airway devices.

Resuscitation with isotonic crystalloid solution is initiated in the prehospital phase of care for patients in shock. Although this principle remains well accepted, the need for intravenous (IV) fluid resuscitation in some patient groups has been questioned and the concept of hypotensive resuscitation has been introduced. The rationale is that overresuscitation before management of bleeding could potentially increase the rate of blood loss by disrupting areas that had become hemostatic. Bickell and associates have performed a prospective trial that compared standard crystalloid administration with the concept of withholding prehospital fluid resuscitation in patients with penetrating torso trauma. The group of patients who had resuscitation withheld until reaching the hospital had a lower mortality than the immediate resuscitation group. These results are intriguing, but the study represented a unique cohort of penetrating trauma patients in an urban setting, with short transport times to definitive care. Nevertheless, it suggests that prehospital fluid resuscitation be judiciously administered to support some minimal level of perfusion to support the maintenance of hemostasis.

Finally, recent military experience has reintroduced the use of tourniquets for prehospital extremity hemorrhage control. For some time, tourniquets were infrequently used because of concern about muscle and nerve injury. Recent advances in device development and provider education have lessened the associated risk and have again demonstrated the potential benefit of tourniquets in certain situations. Several series now have demonstrated improved outcomes related to the use of tourniquets in the military theater. Many prehospital agencies are now including tourniquets on standard equipment lists so that they may be used when confronted with a patient with devastating extremity injuries with uncontrolled arterial hemorrhage. Although many commercial devices are now available, Figure 18-2 illustrates a tourniquet that can be used in the prehospital setting.

**INITIAL ASSESSMENT AND MANAGEMENT**

Since its inception over 30 years ago, the Advanced Trauma Life Support (ATLS) course has presented a safe approach to the initial assessment and management of the injured patient. ATLS has been widely adopted as the standard approach in most trauma centers. All physicians who provide initial care to trauma patients should complete the ATLS course to become familiar with the concept of rapidly identifying and addressing life-threatening conditions during the initial patient assessment. Furthermore, ATLS teaches three important concepts that greatly enhance the ability to manage injured patients, regardless of where care is provided:

1. Treat the greatest threat to life first.
2. The lack of a definitive diagnosis should not delay the application of an indicated urgent treatment.
3. An initial, detailed history is not essential to begin the evaluation of a patient with acute injuries.

The initial assessment follows a well-defined order that is based on the patient’s risk of death. At this time, the identification of life-threatening conditions requires immediate intervention. This initial assessment and management, also termed the primary survey, follows the mnemonic ABCDE (Fig. 18-3):

- **Airway** and cervical spine protection
- **Breathing**
- **Circulation**
- **Disability or neurologic condition**
- **Exposure and Environmental control**

Finally, the safety of the health care team is of utmost importance. Therefore, prior to any patient contact, personal protective equipment must be donned to reduce the risk of infectious disease transmission.

**Airway**

On receiving an injured patient in the emergency department, the status of the patient’s airway should be immediately assessed. This is best achieved by eliciting a verbal response, because speaking patients are typically able to protect their airway. The inability to speak indicates severe mental status depression or some obstruction to air flow through the upper airway. In either of these situations, however, the patient is frequently unable to maintain an adequate airway to support acceptable oxygenation and ventilation. Further indicators of airway compromise include noisy breathing, severe facial trauma, specifically with oropharyngeal blood or foreign body, and patient agitation. A determination of the adequacy of the airway should be completed within seconds of the patient’s arrival, as well as a decision to obtain better airway control if necessary. Even if an airway is thought to be secure, frequent reassessment for decompensation and the development of airway compromise is paramount.

Also of importance during this time is protecting the cervical spine. Injured patients should be suspected of having a cervical spine injury until a thorough evaluation can be completed to eliminate this possibility. Cervical spine protection includes the use of a hard cervical collar and the maintenance of the log roll technique for all patient movement. Spine protection during patient transportation can be augmented by the use of a long spine board but patients should be removed from these devices shortly after emergency department arrival to prevent the development of pressure sores, which can occur within a short period.
of time. During airway assessment and intervention, the anterior portion of the collar can be removed to facilitate exposure and airway manipulation but manual stabilization should be provided by an assistant throughout this period.

Immediate airway adjuncts include supplemental oxygen, oropharyngeal and nasopharyngeal airways, and bag valve mask ventilation. These can be applied quickly to support the failing patient while preparing to secure a more definitive airway. The definitive airway of choice for most injured patients is oral endotracheal intubation provided using a rapid-sequence technique. With cricoid pressure applied, the patient is provided a sedative and fast-acting neuromuscular blocker such as succinylcholine to maximally enhance glottic visualization. Direct laryngoscopy and intubation are performed, with care taken to avoid cervical spine motion. Endotracheal tube position must be confirmed using chest and abdomen auscultation, end-tidal carbon dioxide measurement, and ultimately a chest radiograph. The presence of highly experienced airway personnel can be extremely advantageous and may be an important component of the trauma alert system.

Several recent developments have broadened the capabilities of airway physicians when challenged with a difficult airway. The gum elastic bougie has been shown to improve the rate of successful intubation, especially in the setting of a challenging airway. For injured patients who cannot undergo cervical extension, require cricoid pressure, or have upper airway injuries, the normal view of the glottis may be obscured. In this setting, the bougie can be placed with a limited view of the vocal cords, resulting in an improved rate of appropriately placing an endotracheal tube. Another rescue technique that should be remembered in the setting of an inability to intubate successfully is the use of a blind insertion airway device. Some commonly used devices include the laryngeal mask airway (LMA), multilumen esophageal airway (Combimask), and laryngeal tube airway (King LT-D). These are typically placed blindly and function essentially by occluding the esophagus and the posterior pharynx, allowing assisted ventilation to pass selectively down the trachea. These have been found to be easy to place and are valuable tools in a rescue situation.13

If a difficult airway requires the intubating physician to progress to a backup plan, preparation for a surgical airway should begin. A cricothyroidotomy can be performed with limited equipment and should commence prior to cardiovascular collapse. The inability to maintain oxygenation with a bag valve mask between intubation attempts is a reasonable indication for establishment of a surgical airway. To perform a

![FIGURE 18-3 Algorithm for the initial assessment of the injured patient. BP, Blood pressure; HR, heart rate; RR, respiratory rate.](image-url)
a tube thoracostomy, depending on the availability of equipment and supplies. Massive hemothorax may also require urgent placement of a tube thoracostomy and severe pulmonary contusion can only be managed with aggressive mechanical ventilation, often with elevated levels of positive end-expiratory pressure (PEEP). With severe pulmonary contusion one should resist continuously disconnecting the ventilator to suction or bag the patient when oxygenation will only improve with uninterrupted PEEP.

Circulation
After respiratory stabilization, an immediate assessment for cardiovascular compromise is completed. Simply, the physician must determine whether the injured patient is in shock. Box 18-3 lists the most common immediate indicators of shock. It is important to recognize that a patient can be in shock before developing hypotension because this is one of the last findings before complete cardiovascular collapse. Cardiovascular dysfunction in injured patients is secondary to hemorrhage in most patients. In less common situations, a spinal cord injury (neurogenic shock), or preinjury heart failure or sepsis could be the cause. On recognition of shock, resuscitation is immediately initiated with 1 to 2 liters of warm crystalloid solution infused through two large-bore, short, peripheral IV catheters. A rapid assessment for the source(s) of blood loss is then completed. It may be valuable to approach this assessment by recognizing the five major locations for exsanguinating blood loss: chest, abdomen, retroperitoneum (often a pelvic fracture), multiple long bone fractures, and external sites. Immediately, a brief physical examination will identify long bone fractures and sources of external hemorrhage. A chest radiograph will evaluate for thoracic blood loss and a pelvic radiograph will identify a pelvic fracture. The focused abdominal sonography in trauma (FAST) scan or diagnostic peritoneal lavage (DPL) for gross blood can be obtained to evaluate for intra-abdominal bleeding. The FAST scan is a rapidly obtainable ultrasound that assesses for fluid within the abdomen. The FAST scan assesses the hepatorenal, splenorenal, and pelvic spaces for fluid which in the setting of trauma most likely represents blood. A FAST scan can be performed quickly in the trauma bay by the surgeon and can be rapidly repeated if necessary. Figure 18-5 demonstrates blood in the hepatorenal space on FAST scan.

After the initial 1- to 2-liter crystalloid bolus is infused, patients are reassessed for response by determining whether the indicators of shock have improved. Patients who respond favorably can then continue to undergo a standard evaluation to identify their injuries. It is important to decrease the administered IV fluid to a maintenance rate so that signs of ongoing

**Breathing**
Breathing is rapidly assessed by visualizing or palpating the chest, auscultating breath sounds, and measuring oxygen saturation. Limited respiratory effort or dyspnea are indicative of the need for airway stabilization and ventilatory support. Inability to ventilate the patient adequately could be secondary to tension pneumothorax, massive hemothorax, or flail chest with pulmonary contusion. Tension pneumothorax should be recognized on the primary survey and radiographic confirmation is not required prior to treatment. Deviation of the trachea in the sternal notch, in combination with unilaterally absent or diminished breath sounds and cardiopulmonary compromise, is diagnostic of a tension pneumothorax. Thoracic decompression should immediately be performed with a large-bore needle–angiocatheter or

**FIGURE 18-4** Technique of cricothyroidotomy. The cricothyroid membrane is identified by palpation (A) and a transverse incision is made over the membrane (B). The incision and dissection are continued through the cricothyroid membrane and the cricothyroidotomy is spread, allowing the passage of a tracheal tube.

**BOX 18-3 Indicators of Shock in the Injured Patient**

<table>
<thead>
<tr>
<th>Agitation, confusion</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tachycardia</td>
</tr>
<tr>
<td>Tachypnea</td>
</tr>
<tr>
<td>Diaphoresis</td>
</tr>
<tr>
<td>Cool, mottled extremities</td>
</tr>
<tr>
<td>Weak distal pulses</td>
</tr>
<tr>
<td>Decreased pulse pressure</td>
</tr>
<tr>
<td>Decreased urine output</td>
</tr>
<tr>
<td>Hypotension</td>
</tr>
</tbody>
</table>

**Circulation**
After respiratory stabilization, an immediate assessment for cardiovascular compromise is completed. Simply, the physician must determine whether the injured patient is in shock. Box 18-3 lists the most common immediate indicators of shock. It is important to recognize that a patient can be in shock before developing hypotension because this is one of the last findings before complete cardiovascular collapse. Cardiovascular dysfunction in injured patients is secondary to hemorrhage in most patients. In less common situations, a spinal cord injury (neurogenic shock), or preinjury heart failure or sepsis could be the cause. On recognition of shock, resuscitation is immediately initiated with 1 to 2 liters of warm crystalloid solution infused through two large-bore, short, peripheral IV catheters. A rapid assessment for the source(s) of blood loss is then completed. It may be valuable to approach this assessment by recognizing the five major locations for exsanguinating blood loss: chest, abdomen, retroperitoneum (often a pelvic fracture), multiple long bone fractures, and external sites. Immediately, a brief physical examination will identify long bone fractures and sources of external hemorrhage. A chest radiograph will evaluate for thoracic blood loss and a pelvic radiograph will identify a pelvic fracture. The focused abdominal sonography in trauma (FAST) scan or diagnostic peritoneal lavage (DPL) for gross blood can be obtained to evaluate for intra-abdominal bleeding. The FAST scan is a rapidly obtainable ultrasound that assesses for fluid within the abdomen. The FAST scan assesses the hepatorenal, splenorenal, and pelvic spaces for fluid which in the setting of trauma most likely represents blood. A FAST scan can be performed quickly in the trauma bay by the surgeon and can be rapidly repeated if necessary. Figure 18-5 demonstrates blood in the hepatorenal space on FAST scan.

After the initial 1- to 2-liter crystalloid bolus is infused, patients are reassessed for response by determining whether the indicators of shock have improved. Patients who respond favorably can then continue to undergo a standard evaluation to identify their injuries. It is important to decrease the administered IV fluid to a maintenance rate so that signs of ongoing

**Breathing**
Breathing is rapidly assessed by visualizing or palpating the chest, auscultating breath sounds, and measuring oxygen saturation. Limited respiratory effort or dyspnea are indicative of the need for airway stabilization and ventilatory support. Inability to ventilate the patient adequately could be secondary to tension pneumothorax, massive hemothorax, or flail chest with pulmonary contusion. Tension pneumothorax should be recognized on the primary survey and radiographic confirmation is not required prior to treatment. Deviation of the trachea in the sternal notch, in combination with unilaterally absent or diminished breath sounds and cardiopulmonary compromise, is diagnostic of a tension pneumothorax. Thoracic decompression should immediately be performed with a large-bore needle–angiocatheter or

**FIGURE 18-4** Technique of cricothyroidotomy. The cricothyroid membrane is identified by palpation (A) and a transverse incision is made over the membrane (B). The incision and dissection are continued through the cricothyroid membrane and the cricothyroidotomy is spread, allowing the passage of a tracheal tube.

**BOX 18-3 Indicators of Shock in the Injured Patient**

<table>
<thead>
<tr>
<th>Agitation, confusion</th>
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<tbody>
<tr>
<td>Tachycardia</td>
</tr>
<tr>
<td>Tachypnea</td>
</tr>
<tr>
<td>Diaphoresis</td>
</tr>
<tr>
<td>Cool, mottled extremities</td>
</tr>
<tr>
<td>Weak distal pulses</td>
</tr>
<tr>
<td>Decreased pulse pressure</td>
</tr>
<tr>
<td>Decreased urine output</td>
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<tr>
<td>Hypotension</td>
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Resuscitative thoracotomy can be dangerous for providers and costly to perform. Therefore, studies have attempted to identify patient groups that have a chance of survival following resuscitative thoracotomy to establish when the procedure is indicated. Patients who have demonstrated more favorable results are those with penetrating thoracic injuries who have signs of life on reaching the emergency department. An assessment of all applicable studies yielded a survival rate of 11.2% after resuscitative thoracotomy for penetrating chest injury. Blunt trauma patients have uniformly dismal results and therefore are not candidates, except in the most select situations. Survival rates of 1.6% were noted when appropriate studies were pooled, and most of these survivors had a poor neurologic outcome. Patients with stab wounds demonstrate better outcomes than gunshot wounds because of the higher incidence of pericardial tamponade without major cardiac injury which may be more likely to respond to pericardial decompression. Signs of life suggesting potential response to resuscitative thoracotomy include pupillary reactivity, spontaneous respiratory effort, palpable pulses, extremity movement, and cardiac electrical activity. Performing a resuscitative thoracotomy mandates having surgical support personnel who can perform definitive repair of thoracic injuries if spontaneous circulation is successfully resumed.

**Secondary Survey**

A head to toe evaluation is completed on all stable patients after the primary survey. All body regions are thoroughly examined to identify injuries or the need for further evaluation. At this time, a more detailed neurologic evaluation can be completed and abnormalities of the face and neck identified. This includes posterior surfaces that are more difficult to visualize and may be obscured by the cervical collar. The torso is examined, especially with respect to pulmonary dysfunction and abdominal tenderness. Seatbelt or other superficial injury to the neck and abdomen may prompt further evaluation. The pelvis is assessed for tenderness, with care taken to avoid excessive compression because this technique to identify stability may only disrupt hemostasis. A rectal examination with a nonbloody glove to assess the prostate and the presence of gross gastrointestinal (GI) blood should be included. The extremities are evaluated for closed or open deformities and each joint should be manipulated to identify abnormalities. Careful assessment of distal perfusion is extremely important, especially in the presence of an associated extremity injury. This frequently includes an evaluation of pulse quality and blood pressure comparison between extremities. The patient should be rolled to assess the spine for deformity or tenderness and the long spine board can be removed at this time. Penetrating mechanisms require meticulous surveillance for all penetrating injuries, especially those that may be difficult to identify in areas such as the scalp, mouth, axilla, perineum, and throughout the back. On identification of these injuries, labeling with a radiopaque marker may allow localization on imaging studies.

**MANAGEMENT OF SPECIFIC INJURIES**

**Damage Control Principles**

Historically, in many centers, trauma patients who required immediate operation for life-threatening injuries would undergo surgery until all injuries were definitively repaired. Some patients would experience progressive physiologic derangement during these operations, often developing hypothermia, coagulopathy,
and metabolic acidosis, a combination that has become labeled as the deadly triad or the bloody vicious cycle. To avoid certain death, this cycle must be halted by quickly managing bleeding and providing aggressive resuscitation. In 1993, Rotondo and associates\(^5\) coined the term **damage control** to describe an approach to managing patients who were progressing rapidly toward death as their injuries were being definitively repaired. Damage control includes immediate surgical control of hemorrhage and contamination without immediate definitive reconstruction. All surgical bleeding is controlled and intra-abdominal or intrathoracic packing is frequently required to achieve hemo-stasis. Hollow visceral resection with temporary GI discontinuity is also commonly used. The chest or abdomen is then temporarily closed, frequently using a vacuum-type closure method. The patient is aggressively resuscitated in the intensive care unit with the goal of achieving adequate cardiopulmonary function and metabolic hemostasis. On improvement in body temperature, coagulopathy, and acidosis, definitive reconstruction of injuries can occur, followed by chest or abdominal closure when feasible. Initially, the concept of damage control was used for severe abdominal injuries but the principles have been applied to injuries of the chest, pelvis, and extremities. Using a similar approach, some have even advocated damage control orthopedics, which is based on the theory that rapid fracture stabilization may reduce the inflammatory response to injury and result in fewer long-term sequelae.

Recently, traditional methods of resuscitation immediately after injury have been questioned. Born out of military experience, an approach now called damage control resuscitation has evolved, with promising early results. In damage control resuscitation, replacement of lost blood is provided as a more equivalent distribution of all blood components. The military experience found that resuscitation with equal amounts of packed red blood cells, plasma, platelets, and cryoprecipitate resulted in preventing severe coagulopathy, which was associated with less physiologic derangement after severe injury.\(^6\) Although some studies have reported improved outcomes with this approach, others have questioned the validity of these findings when applied to civilian patient populations. Nevertheless, many trauma centers have implemented this approach. Prospective trials are greatly needed to definitively evaluate this practice.

**Injuries to the Brain**

Traumatic brain injuries (TBIs) remain one of the greatest causes of death and disability despite significant improvements in the care of these injuries over the last several decades. Injuries to the brain are common with a substantial percentage resulting in death or permanent disability. Commonly, the outcome of a patient with multiple injuries is dictated by the impact of the brain injury. According to data from the CDC, 1.4 million brain injuries are sustained each year, with 1.1 million evaluated in U.S. emergency departments.\(^7\) Falls are the most common cause of brain injuries, with those at the extremes of age being the most vulnerable to this mechanism. The mortality rate for the 235,000 patients with TBI that require hospitalization is 21.3% and the number of people experiencing permanent TBI-related disability exceeds 80,000 each year.

**Mechanism and Pathophysiology**

Injuries to the brain result from direct transmission of energy to the cranium and the underlying brain tissue, as well as damage resulting from movement of the brain within the rigid cranial vault. Compression of brain tissue can also result from tearing of intracranial blood vessels, which causes accumulation of blood. Secondary brain injury can occur following the initial insult and results from ischemia and compression by adjacent tissue edema. Because of the rigidity of the bony cranium, the volume within the skull remains constant. The Monro-Kellie doctrine states that any increase in the volume of intracranial contents results in an elevation of intracranial pressure with an associated decrease in the volume of other tissues, such as the brain parenchyma and cerebrospinal fluid. Figure 18-6 depicts the relationship between intracranial volume and pressure, which explains why injury resulting in increased intracranial blood and edema can have such a detrimental effect on the surrounding brain tissue. Epidural hematomas (Fig. 18-7) typically result from a lateral fracture of the cranium causing bleeding from the middle meningeal artery or a nearby vessel. The classic clinical course includes a brief loss of consciousness followed by a lucid interval, during which time the hematoma is expanding. Ultimately, symptoms again develop and can be profound without intervention. When identified and treated early, patients with epidural hematomas can have favorable outcomes because the hematoma itself is usually not associated with underlying brain parenchymal injury. This is in distinction to subdural hematomas, which commonly are associated with severe underlying brain tissue injury (Fig. 18-8). Subdural hematomas are believed to result from tearing of the bridging veins between the dura and cerebral cortex. The hematoma can be compressive but it is frequently the underlying brain contusion and axonal injury that dictate the outcome after these injuries. Subarachnoid hemorrhage after TBI is common and in itself has little deleterious effect. The presence of blood in the subarachnoid space likely is a reflection of the presence of a TBI, which should prompt surveillance. Parenchymal contusions of brain tissue result from a direct blow to the cranium or from movement of the brain within the rigid cranial vault, resulting in injury on the opposite side, also described as a contra-coup injury. Typically, the blood and hematoma associated with these contusions are not overly

**Figure 18-6** The Monro-Kellie doctrine describes the increase in intracranial pressure as intracranial volume increase secondary to hemorrhage or edema. This relationship of pressure to volume is a result of the rigid cranial vault, which exhibits a fixed volume.
large but the edema that develops over the subsequent days can be profound and a major source of secondary brain injury. Finally, diffuse axonal injury describes the phenomenon of disruption of the axon from the neuronal body secondary to severe rotational forces that are believed to create a shearing effect. Frequently, the magnitude of this type of injury cannot be appreciated on imaging and the ultimate severity is determined clinically during the weeks that follow. Diffuse axonal injury may be suggested on imaging by the presence of scattered punctuate hemorrhages within the parenchyma and, at times, a loss of the differentiation of gray and white matter.

**Immediate Management**

Prevention of secondary brain injury is of highest priority as soon as a patient with a TBI is encountered. Given our current capabilities, little can be done to reverse the effects of the primary brain-injuring process, but intervention can be provided to prevent secondary insult. At the most basic level, this includes ensuring that the injured brain receives adequate blood flow to supply necessary quantities of oxygen. Therefore, emphasis must be placed on maintaining the ABCs throughout all prehospital and hospital phases of care. This includes early recognition of severe TBI, with immediate establishment of an acceptable airway and initiation of physiologic ventilatory support. Hemorrhage control and resuscitation should be initiated to prevent hypoperfusion, which can be highly detrimental to the injured brain. Determination of the GCS can be valuable to compare the patient’s neurologic condition throughout the continuum of care. Patients known to be on antithrombotic therapy urgently need reversal of the anticoagulant effects, which may worsen intracranial hemorrhage. Because of the time-dependent nature of certain intracranial injuries, decreasing the time from injury to the operating room can be lifesaving for some patients. Therefore, hospitals without neurosurgical support should quickly assess whether they have the capability to care for a patient with a presumed TBI and then make the appropriate transfer arrangements. This should be a high priority and should not be delayed to obtain studies that will have no immediate impact on the care of the patient.

**Evaluation**

The evaluation of TBI begins during the primary survey, when a brief assessment of neurologic function is completed. Typically, this includes determination of the GCS, with emphasis on elucidating the best motor function, because this can be most predictive of neurologic function. The inability to follow commands is a valuable indicator of a severe brain injury. An assessment of the character of the pupils is also included because this can be indicative of progressive compression within the cranium that is impinging on the cranial nerves. If possible, a neurological examination should be performed before it is obscured by sedating or paralyzing agents such as those used for intubation.

Although the management of airway compromise and shock are of highest priority, patients with a TBI benefit from early imaging of the cranium after stabilization. Computed tomography (CT) of the head without IV contrast is the most important diagnostic study during the initial evaluation of TBI because it provides a highly sensitive determination of acute intracranial pathology. When reviewing a CT scan of the head, acute blood appears as high-density fluid that can be further...
characterized by location within the cranium. Intraparenchymal contusion as well as edema with mass effect can also be identified by cranial CT. Because the presence of certain hematomas on CT scans may prompt emergent craniotomy, it is important to expedite imaging as soon as stability is ensured in all patients with a suspected TBI. Imaging of the cranium with magnetic resonance imaging (MRI) may be able to provide better anatomic detail, especially in the setting of ischemia, but has no role in the initial evaluation of the brain injured patient.

Management

Early cranial CT will identify patients who might benefit from operative intervention. Neurosurgical consultation should be obtained early to allow for rapid transfer to the operating room when necessary. Findings on cranial CT that may benefit from urgent surgery include epidural and subdural hematomas, especially in the setting of an associated mass effect. Severely depressed skull fractures may also benefit from early operation to manage hemorrhage and elevate the depressed bone. Epidural and subdural hematomas are managed with craniotomy, followed by evacuation of hematoma and cessation of intracranial bleeding. Because of the underlying parenchymal injury, significant edema can often develop after hematoma evacuation, especially in the setting of a subdural hematoma. Following surgery, patients will frequently require ongoing surveillance of neurologic function and management of intracranial hypertension. Occasionally, patients with intracranial hypertension refractory to all nonoperative interventions are considered for decompressive craniectomy, which includes removal of a portion of the cranium and may include parenchymal resection in severe cases.

Most patients with intracranial hemorrhage require close monitoring of neurologic function and vital signs, which is usually best performed in a higher level of care setting, such as the intensive care unit. Guidelines published by the Brain Trauma Foundation provide an excellent assessment of the literature and represent the most comprehensive, evidence-based recommendations available. Secondary brain injury should be prevented by ensuring adequate cardiovascular and pulmonary function. Many patients with severe TBI require measurement of the intracranial pressure (ICP) to guide management, which is aimed at reducing associated brain tissue edema. Cerebral perfusion pressure (CPP), which is the difference between the mean arterial pressure and the ICP, is also commonly used to guide severe TBI management. Although many physicians preferentially use ICP or CPP to direct management, it has been determined that neither one is superior to the other. It has been recognized that the overaggressive treatment of CPP may be deleterious. Figure 18-9 demonstrates an approach to the management of the patient with a severe TBI.

To manage elevations in ICP, several interventions have been suggested. Placement of a ventriculostomy allows both the measurement of ICP and the drainage of cerebrospinal fluid. Ventilated patients benefit from mild hyperventilation, with the goal being maintenance of the Pco₂ between 30 and 35 mm Hg because the use of more profound hyperventilation has been found to be deleterious. Hyperventilation must be avoided. Sedation aimed at reducing ICP is a valuable tool, although the depth of suppression should be kept at a minimum to ensure a productive neurologic examination. Hyperosmolar therapy with mannitol or, more recently, hypertonic saline that functions by reducing brain tissue edema is frequently useful. Administration of these agents requires monitoring of serum osmolality to prevent severe electrolyte derangement. Occasionally, paralysis and barbiturate coma induction are implemented but should be used only in cases refractory to other interventions. Finally, it has been well established that corticosteroid administration has no role in the management of TBI.

Injuries to the Spinal Cord and Vertebral Column

Spinal cord injuries (SCIs) have profound immediate and long-term effects on patients often resulting in years of disability. Except for high cervical spine injuries, mortality directly related to SCIs is low, although the associated morbidity is substantial and irreversible. Many patients sustaining SCIs are young and therefore experience many years of debilitation. In the NTDB, approximately 1% of blunt and penetrating trauma patients sustained a SCI, with an associated mortality of 13.3% and 15.1%, respectively. Motor vehicle crashes (MVCs) remain the leading cause of SCIs whereas in penetrating injuries, gunshot wounds cause the vast majority. Vertebral column fractures without SCI are 10-fold more common than those that occur with a SCI. Again, most commonly caused by MVCs, vertebral column fractures are present in 11.8% of all blunt trauma patients in the NTDB and are associated with a mortality rate of 6.3%. Approximately one third of these fractures involve the cervical spine.

Injuries to the spinal cord can occur after blunt or penetrating mechanisms. Blunt trauma to the spine can result in cord injury through direct impingement or indirect manipulation. Fractures and dislocations can reduce the size of the spinal canal and cause direct tissue damage or secondary injury through ischemia, bleeding, or edema. The spinal cord can also sustain injury through mechanisms that distract or severely rotate the cord, causing neuronal damage. Penetrating mechanisms directly lacerate the spinal cord tissue or cause adjacent injury and indirect damage. Occasionally, injury to the spinal cord can occur without abnormality of the vertebral column identified on imaging. The phenomenon known as spinal cord injury without radiographic abnormality (SCIWORA) can be extremely frustrating because the lack of bony injury can result in missed opportunities to prevent neurologic injury. Fractures of the vertebral column can occur after almost any form of physical force. Common mechanisms include flexion and extension, especially in the cervical spine, as well as compressive forces that commonly affect the lumbar spine. A Chance fracture is a well-described pattern with transverse disruption through all vertebral elements that occurs most commonly during an MVC. During a high-speed frontal crash, an occupant wearing a seatbelt above the iliac crest experiences flexion and distraction of a lumbar vertebrae, resulting in this fracture pattern (Fig. 18-10).

Immediate Management

Management of injuries involving the spine begins immediately on prehospital personnel arrival. Spinal immobilization with a rigid cervical collar and a long spine board should be performed immediately and should include manual assistance throughout all patient transfers. All blunt and select penetrating trauma patients are assumed to have an injury to the spine until a proper
Evaluation can exclude the diagnosis. Management of the airway with support of ventilation may be required in the setting of high cervical spine injuries. Injuries to the spine superior to C5 may have varying degrees of respiratory depression because of paresis of the phrenic nerves. Patients with neurogenic shock caused by a loss of sympathetic tone require intravascular volume expansion and, at times, initiation of vasopressors early in the course of treatment. Typically, this is indicated by the presence of hypotension in a patient with warm, well-perfused extremities that also demonstrate decreased motor function. Finally, depending on spine surgeon preference, corticosteroid therapy may be initiated during the initial time period in the emergency department, although this practice remains extremely controversial.

**Evaluation**

During the primary survey, an assessment of extremity movement can evaluate for a SCI grossly. A more comprehensive assessment should occur during the secondary survey, with a detailed determination of neurologic function obtained in those patients who demonstrate a deficit. The level of sensory loss should be determined, as well as the muscle groups that exhibit weakness or paralysis. This information may serve to assist in identifying the location of the injury but also to track progression of symptoms, which may affect therapeutic decisions. SCIs

**FIGURE 18-10** Chance fracture on lumbar spine CT scan, sagittal view. Note the fracture involvement of all posterior elements (*arrow*).
are deemed complete if all neurologic function below a specific cord level is absent or incomplete if there is motor or sensory function identified below this level. Spine surgeons’ consultation should be done early so that they are actively involved in this evaluation. Examination may also reveal tenderness over the injured vertebrae or the presence of a deformity consistent with disruption of the vertebral column. Patients who have no findings on examination, demonstrate no decreased level of consciousness, and have no distracting injuries can undergo clearance of the spine by clinical means alone.

Further evaluation of the spine typically involves CT of the cervical, thoracic, and lumbar vertebral bodies. Although plain radiographs of the spine are acceptable, the high-quality images and rapid availability associated with CT have made this the modality of choice in most emergency departments. Visualization of the cervicothoracic junction on plain radiographs can be extremely challenging, especially in larger patients, and can often require numerous repeat studies. For this reason, many have transitioned to obtaining a dedicated cervical spine CT during the initial imaging of the patient. CT also provides the ability to reconstruct the images into sagittal and coronal planes to provide even better anatomic visualization. SCIs are less well delineated on CT than bony injuries but are suggested by the presence of spinal canal compromise and soft tissue edema identified adjacent to the spinal cord. Figure 18-11 demonstrates a severe cervical spine fracture with subluxation and anterior displacement.

The thoracic and lumbar vertebral columns are more conducive to imaging with plain radiography than the cervical spine. Identification of the alignment of the vertebral bodies as well as an assessment of the vertebral height are the main features evaluated on plain radiography. Many centers obtain CT scans of the chest, abdomen, and pelvis during the radiographic evaluation for truncal injuries. These images can be reformatted to focus on the thoracic and lumbar spines in the sagittal and coronal planes. The anatomic detail provided by these images is excellent and has been shown to be more sensitive for bony injury than plain radiographs. Because these studies require no further imaging and provide superior visualization, many centers have now abandoned plain radiographs in exchange for reformatted thoracic and lumbar spine CT scans. The presence of a significant injury identified on reformatted imaging may require a dedicated study to formulate an operative plan better. Although CT is the study of choice for evaluating the bony structures, assessment of the spinal cord frequently requires MRI to visualize injured soft tissue better. Obtaining these images, especially in the acute setting, must be carefully considered with respect to the patient’s overall level of stability.

Management
As noted, the spine requires protection with strict immobilization throughout the entire evaluation until injuries can be ruled out. Typically, this includes the use of a hard collar and maintenance of the log roll technique when movement is required. Although a long spine board is generally used during the transport of patients in an ambulance, it is important to remove it as soon as possible to prevent the development of pressure wounds, which can develop quickly when a patient is lying on a rigid device. On recognizing the presence of a SCI, a spine surgeon consultation should be obtained promptly. In facilities that have no spine surgery services available, arrangements for transfer should begin immediately. Further studies and interventions should only occur if the results will have an immediate impact on the care provided. For example, imaging to identify an associated vertebral column fracture will have no effect on care if a spine surgeon is not available and therefore transfer should not be delayed. SCIs with neurogenic shock, occurring most commonly with cervical injuries, require resuscitation because of a loss of sympathetic tone. Neurogenic shock frequently responds to volume expansion with crystalloid solution but occasionally requires vasopressor agents such as dopamine or epinephrine. Hypotension should be avoided because it may contribute to cord ischemia and progression of the SCI. The value of corticosteroid administration has been extensively studied but remains controversial. Several large randomized trials have demonstrated small improvements in recovery after methylprednisolone administration, especially when initiated early after injury. Others investigators have been unable to reproduce these results and have found an increased incidence of steroid-related complications with methylprednisolone therapy. Therefore, most authors agree that steroids remain an option that should be considered after consultation with the spine surgeon. When administered, methylprednisolone is provided as a bolus of 30 mg/kg body weight followed by an infusion of 5.4 mg/kg/hr for 23 hours if the bolus was given within 3 hours of injury. The infusion duration is extended to 48 hours if the bolus was administered between 3 and 8 hours after injury whereas SCIs that occurred more than 8 hours prior should not be treated.

Cervical fracture-dislocation injuries may benefit from the application of traction in the emergency department to restore vertebral column alignment. Based on the injury pattern and associated injuries, some SCIs benefit from early operative
decompression to reduce cord impingement, as determined by the spine surgeon. Other injuries may require fixation because of instability on a semielective basis after immediate patient care needs are addressed. Fractures without instability may require only immobilization with a hard collar or brace over a several-week time period. Table 18–4 lists commonly encountered vertebral column fractures with management options. It is important that any patient with an SCI or significant vertebral column injury be monitored closely for changes in neurologic examination that might prompt urgent intervention.

**Injury to the Maxillofacial Region**

Facial injuries are common but rarely life-threatening. The main concern during the initial evaluation and management of facial trauma is airway maintenance and bleeding. Injuries to the face were identified in 24.8% of NTDB cases, with an associated mortality of 4.7%. It is likely that a significant majority of these deaths were caused by associated TBIs because their simultaneous presence is high. Facial injuries can result from direct impact during a blunt mechanism, such as an MVA or fall. Fractures of the facial bones and soft tissue injuries predominate. Lefort fractures represent a specific pattern of facial bone injuries that consist of three variations of midface disruption from the surrounding facial bones. Despite their frequent description, Lefort fractures are uncommonly identified. Penetrating mechanisms such as gunshot and knife-related wounds are not uncommon and can result in large soft tissue injuries, especially with the passage of a bullet through the face. Injuries to the face can also result in disruption of sensory function when associated with eye, nose, ear, or mouth involvement.

**Immediate Management**

Establishment of a secure airway is the greatest concern with facial injuries, especially those with severe lower face soft tissue and bony involvement. Early intubation prior to the development of significant edema may be lifesaving. Securing the airway may be complicated by distortion of the anatomy and by presence of blood and debris in the mouth and posterior pharynx. The application of multiple airway options, including a surgical approach, may be necessary. Control of bleeding is also of great importance given the extensive vascularity of the face. Bleeding can be from soft tissue or exposed bone edges and should be initially treated with direct pressure and resuscitation. Suture ligation of identified bleeding vessels or rapid closure of wounds with suture or staples can be highly effective. Frequently, bleeding from the face is exacerbated by hypothermia and coagulopathy, which should be aggressively prevented or treated.

**Evaluation**

Most facial injuries are evident on physical examination. Soft tissue injuries can be characterized and the involvement of facial organs assessed. The eyes should be examined for changes in visual acuity and the presence of diplopia. The condition of the globe and the surrounding orbit requires careful evaluation for rupture or extraocular muscle entrapment, which would require urgent treatment. Injury to the external ears and nose are also identified on physical examination. The stability of the midface and jaw should be assessed, as well as the condition and proper occlusion of the dentition and alveolar ridge. Deformities of the forehead and cheeks indicate underlying frontal bone and maxillary fractures, respectively. If possible, function of the facial nerve should be assessed by testing the motor groups of the face.

CT performed with thin cuts provides excellent visualization of the facial bones and is the most common modality used in the evaluation of the face. Sagittal and coronal, as well as three-dimensional reconstructions, can aid in the thorough assessment of the bones and soft tissue. Severe external injury to the face should prompt obtaining a facial CT scan. Patients who undergo head CT can have the facial bones assessed for obvious fracture or fluid within the sinuses, which should suggest the need for facial CT. Critically injured patients might have facial injury suggested by physical examination after severe injuries have been managed, at which time evaluation with facial CT can be performed.

**Management**

Severe soft tissue injuries and fractures to the face frequently benefit from the assistance of maxillofacial surgery specialists.
to assist in management. As noted, airway management and bleeding are the greatest priority. Bleeding frequently responds to direct pressure or suture closure of the wound although, in severe cases, angiography with embolization of bleeding facial blood vessels may be necessary. Lacerations can frequently be closed with local anesthesia using deep absorbable sutures followed by closure of the epidermis with 5-0 or 6-0 interrupted or running sutures. Prior to closure, wounds should be debrided to remove all jagged or nonviable skin edges, as well as irrigated with sterile fluid. Closure of lacerations to the lip, nose, ear, and orbit require special consideration to facilitate optimal wound healing.

Management of facial fractures is almost never required acutely. Severely depressed facial bone fractures are the exception because these may involve the underlying brain and require urgent reduction. Large facial wounds may necessitate multiple washouts but the formal reconstruction is still usually delayed. Most maxillofacial fractures are intentionally repaired in a delayed fashion to allow reduction in the associated edema that almost uniformly develops. Large open wounds and fractures involving sinuses or the aerodigestive tract require antibiotics shortly after admission but overextending this course should be avoided. Most fractures benefit from open reduction and internal fixation, typically using screws and plates. The goal of reconstruction is to restore optimal functional and cosmetic results. Orbital fractures with rectus muscle injuries require reconstruction to preserve normal ocular movements. Mandibular fractures are commonly encountered and can be characterized by the anatomic location of the fracture. Minimally displaced fractures can be treated with maxillary-mandibular fixation using wires or bars whereas plating may be necessary for fractures with significant displacement.

**Injuries to the Neck**

The neck can be one of the more overwhelming regions when confronted with severe injury, likely because of the presence of multiple vital structures in close proximity to one another. Nevertheless, as with other areas of the body, addressing neck injuries can be manageable by implementing an organized approach. Although only 1% of all injuries in the NTDB involve the neck, the associated mortality rate is the highest of all regions, reaching 9.7%. Penetrating mechanisms are the most common, with gunshot and stab wounds accounting for most neck injuries. Penetrating injuries can result in direct laceration of vascular and aerodigestive structures, resulting in substantial bleeding or contamination, respectively. Blunt injuries to the neck can cause compression, with fracture of the larynx or trachea. Blunt pharyngeal or esophageal injuries are extremely rare but can result in leakage into the surrounding soft tissue with sepsis if not adequately addressed. Blunt cerebrovascular injuries (BCVIs) involving the carotid arteries commonly result from compression by a seatbelt; the vertebral arteries are vulnerable to severe flexion and extension mechanisms. Injury severity ranges from intimal tears, with or without thrombosis, to full-thickness injury with pseudoaneurysm formation. One of the greatest concerns after BCVIs is stroke secondary to thromboembolism developing from the disrupted vessel wall.

**Immediate Management**

Much of the trepidation related to neck injuries is the urgency commonly related to the initial management. Of greatest primary concern is establishment of a secure airway, especially given the rapidity with which deterioration can occur in the setting of a neck injury. Airway compromise can occur secondary to direct injury to the larynx or trachea, as well as blood or debris within the upper airway. Expanding neck hematomas can quickly compress the upper airway, leading to cessation of adequate ventilation. The presence of an expanding neck hematoma mandates immediate intubation by experienced personnel before complete airway obstruction occurs. Great care should be taken in managing the airway in the setting of a suspected laryngotracheal injury. Patients who are maintaining their own airway should undergo planning that might include intubation or awake tracheostomy in the operating room. Attempted intubation could worsen a tenuous situation and should not be performed without a backup plan, unless in an emergent situation. The surgical airway of choice for an upper airway injury is a tracheostomy because injury to the larynx could make cricothyroidotomy ineffective.

Hemorrhage is the other major concern in the immediate period after neck injuries. Most bleeding can be controlled with direct pressure, at least during transport to the operating room and initiation of neck exploration. Hemorrhage through a penetrating wound should be immediately treated with digital pressure in the wound until operative exposure can be achieved. Resuscitation with blood products should be initiated in the setting of substantial bleeding from the neck because large quantities of blood can be lost quickly. It is of great importance that patients suspected of having a vascular injury be rapidly transferred to the operating room for surgical management of ongoing bleeding.

**Evaluation**

Unstable patients should be taken immediately to the operating room and will therefore undergo the entire evaluation of the neck under direct visualization. Those who are stable on initial evaluation require further assessment for suspected injuries. In the setting of penetrating trauma, evaluation and management of the neck have typically depended on the anatomic location of the injury. For descriptive purposes, the neck can be divided into three zones (Fig. 18-12). Zone I extends from the thoracic inlet to the cricoid cartilage and contains large vascular structures, as well as the trachea and esophagus. Zone II is bordered inferiorly by the cricoid cartilage and superiorly by the angle of the mandible. Zone II is the most accessible surgically and contains the carotid and vertebral arteries, jugular veins, and structures of the aerodigestive tract. Zone III includes the neck between the angle of the mandible and the base of the skull. This zone includes vascular structures that are difficult to expose surgically. Traditionally, injuries to zone II mandated operative exploration whereas zones I and III were evaluated with diagnostic studies to determine the presence of injury. It has since been recognized that only patients with evidence of active bleeding or an obvious aerodigestive injury require mandatory neck exploration. Others, regardless of anatomic location, can be evaluated with diagnostic studies.

In patients undergoing evaluation of penetrating neck trauma, an assessment of the vasculature is required. Frequently, this can be achieved with CT angiography, which can delineate the vascular anatomy of the neck with great accuracy. CT angiography can be performed quickly in the emergency department and is effective at revealing vascular injuries to the neck.
Evaluation for BCVIs has evolved substantially over the last decade. Although initially thought to be extremely rare, the emergence of high-risk screening criteria and improved imaging technology has led to a significant increase in the diagnosis of BCVIs. In 1999, Biffi and coworkers published a set of criteria that accurately identified a group of patients at high risk for BCVIs. Digital subtraction angiography of the carotid and vertebral arteries after penetrating neck trauma is an option for evaluation of the carotid and vertebral arteries after penetrating neck trauma. Evaluation for BCVIs has evolved substantially over the last decade. Although initially thought to be extremely rare, the emergence of high-risk screening criteria and improved imaging technology has led to a significant increase in the diagnosis of BCVIs. In 1999, Biffi and coworkers published a set of criteria that accurately identified a group of patients at high risk for BCVIs. Digital subtraction angiography of the carotid and vertebral arteries was then more readily applied to these high-risk patients, resulting in the identification of BCVIs in over 30% of this cohort. This work led to the establishment of the Denver criteria, which suggests which patients require evaluation for BCVIs. Box 18-4 lists the findings most commonly used to prompt further evaluation. Although originally these injuries were all identified using standard angiography, recent advances in CT angiography have changed how many of these injuries are diagnosed. It appears that the skill of the radiologist is of great importance, but CT angiography has demonstrated a sensitivity and specificity comparable to that of standard angiography. Other studies have questioned the usefulness of CT angiography in this setting, citing a significantly worse ability to detect these injuries. Nevertheless, with the improved logistics of obtaining a CT scan and the more favorable associated risk profile, most centers now rely heavily on CT imaging for BCVI evaluation.

Neck injuries also require an assessment of the aerodigestive tract. This can be achieved by performing bronchoscopy to assess the trachea. Evaluation of the larynx can be challenging and is best accomplished with laryngoscopy. Finally, the esophagus requires evaluation, which is best done by performing contrast esophagraphy and esophagoscopy. Separately, these two studies may miss up to 20% of esophageal injuries, but together almost all injuries will be identified. At times, more severe injuries cannot safely be evaluated with a contrast study and therefore require a thorough endoscopic evaluation. Frequently, information obtained from the neck CT scan will allow the clinician to perform these diagnostic studies selectively when the involvement of a given structure has clearly been avoided.

Management
Shock, active bleeding, expanding neck hematoma, and/or obvious aerodigestive injuries require immediate neck exploration. Neck exploration is most commonly performed using an incision along the anterior border of the sternocleidomastoid muscle on the side of the injury. Occasionally, a collar incision is more versatile, especially if both sides of the neck need exploration. The platysma is divided and the anterior border of the sternocleidomastoid muscle is identified and dissected from the underlying tissue. The internal jugular vein is next identified and exposed. The internal jugular vein is commonly injured and requires direct repair or ligation if closure is not possible. Along the anterior border of the internal jugular vein, the facial vein is identified and exposed. Ligation of the facial vein will allow the deep structures of the neck to be approached. With the internal jugular vein retracted laterally, the carotid sheath is exposed. If necessary, proximal and distal carotid control are obtained and the artery is exposed. Care should be taken to avoid injuring the adjacent vagus nerve and the hypoglossal nerve, which crosses the internal carotid artery superiorly. Injuries to the carotid artery require repair with simple closure or end-to-end anastomosis. Frequently, reconstruction of the carotid artery with a synthetic graft or autologous vein is necessary. In damage control situations, the carotid artery can be ligated if no other options exist.

**BOX 18-4 Indicators of High Risk for Blunt Cerebrovascular Injury**

<table>
<thead>
<tr>
<th>Signs and Symptoms</th>
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<tr>
<td>Expanding neck hematoma</td>
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<tr>
<td>Arterial hemorrhage from neck, nose, mouth</td>
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<tr>
<td>Focal neurologic deficit</td>
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<tr>
<td>Cervical bruit (patient age &lt;50 yr)</td>
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<tr>
<td>Stroke on CT or MRI</td>
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<td>Neurologic deficit unexplained by CT findings</td>
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<table>
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<tr>
<th>Risk Factors</th>
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<tr>
<td>Severe midface fracture, Lefort II or III</td>
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<tr>
<td>Basilar skull fracture involving the carotid canal</td>
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<tr>
<td>Diffuse axonal injury and GCS ≤6</td>
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<tr>
<td>Significant cervical spine fracture or ligamentous injury</td>
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<tr>
<td>Significant soft tissue injury to anterior neck (e.g., seatbelt mark)</td>
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<tr>
<td>Near-hanging with anoxia</td>
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**FIGURE 18-12 Zones of the neck.** Zone 1 extends from the thoracic inlet to the cricoid cartilage. Zone 2 is between the cricoid cartilage and the angle of the mandible. Zone 3 extends from the angle of the mandible to the skull base.
To explore the trachea or esophagus, the carotid artery is retracted laterally and dissection is continued medially. This exploration may be greatly aided by the placement of a nasogastric tube to allow palpation of the esophagus. Injuries to the esophagus should be débrided to expose the entirety of the perforation. Closure can be with one or two layers and meticulous drainage is important. Covering the esophageal repair with viable muscle may be highly beneficial, especially in the setting of adjacent tracheal or vascular repair. In the setting of massive tissue loss or delayed presentation, esophageal diversion with the creation of an esophagostomy may be necessary. Simple tracheal lacerations can be primarily closed with absorbable suture if the injury is small and will approximate in a tension-free fashion. Larger defects require resection and reanastomosis although some anterior tracheal injuries are amenable to tracheostomy creation through the injury. After maturation of the tracheostomy tract, the tube can be removed and closure usually occurs spontaneously.

The treatment of BCVIs has evolved significantly over the last decade. Following the increased recognition of these injuries, it was determined that anticoagulation and antiplatelet therapy substantially reduced the risk of stroke. Typically, patients who are identified as high risk undergo CT angiography or digital subtraction angiography shortly after admission to evaluate for a BCVI. Many patients have a contraindication to immediate anticoagulation and antiplatelet therapy but treatment should be initiated as soon as safely possible, because a significant percentage of strokes occur days to weeks after injury. An approach to the diagnosis and management of BCVIs was recently published by the Western Trauma Association (Fig. 18-13). The suggested treatment includes initiation of anticoagulation, with heparin aimed at achieving a partial thromboplastin time between 40 and 50 seconds. Antiplatelet therapy is another option for those who cannot receive full anticoagulation. After 7 days, a repeat CT angiogram can be obtained and those patients who demonstrate complete healing no longer require therapy. Others require ongoing treatment for 3 months, followed by reevaluation. The presence of a pseudoaneurysm may benefit from endovascular management with stent placement or embolization for vertebral artery injuries.

**Injuries to the Chest**

Thoracic injuries are common, with up to one of five patients presenting with trauma involving the chest. Given that the chest contains the most vital cardiopulmonary structures, these injuries have the potential of being severe. In the NTDB, chest injuries are present in 13.8% of all blunt and 12.2% of all penetrating trauma patients, associated with an overall mortality.
rate of 8.4%. Among patients sustaining blunt thoracic trauma, the mortality is significantly greater, ranging from 9.5% to 47.5%, depending on injury severity. Despite the seriousness of these injuries, most can be treated effectively by basic maneuvers that can be provided in the emergency department. MVAs are the most common cause of blunt thoracic injuries, followed by falls, with injury resulting from the transmission of energy to the chest wall and underlying structures. Direct compression, as well as deceleration and rotational physical mechanisms, contribute to the incidence of thoracic injury. The size and location of the chest make it vulnerable to penetrating mechanisms, such as gunshot and stab wounds. The lungs and mediastinal structures are susceptible to lacerations and perforations when exposed to penetrating trauma.

**Immediate Management**

Many injuries to the thorax require immediate intervention during the primary survey to support cardiopulmonary function. As noted earlier, establishment of a secure airway and ventilatory assistance should occur immediately in patients with respiratory compromise. Poor compliance on ventilation with decreased breath sounds may indicate a tension pneumothorax, which requires urgent placement of a tube thoracostomy. External bleeding should be controlled with direct pressure while resuscitation with crystalloid solution and blood products is initiated. Hemodynamic instability may indicate a tension pneumothorax requiring decompression, hypovolemia requiring hemorrhage control and resuscitation, or cardiac dysfunction secondary to pericardial tamponade, cardiac contusion or myocardial infarction, or coronary air embolism. Evaluation for sources of bleeding should commence and an assessment for pericardial fluid with ultrasound or pericardial window be completed, especially in the setting of penetrating trauma. Based on these initial interventions, decisions regarding subsequent management such as immediate operation can be determined. Cardiac arrest, especially in the setting of penetrating mechanisms, requires resuscitative thoracotomy (see earlier). An approach to the initial evaluation and management of penetrating chest injuries is presented in Figure 18-14.
Evaluation
Most thoracic injuries can be identified with a physical examination and plain chest radiography. Physical examination will reveal superficial injuries, including chest wall defects and penetrating wounds. Overall respiratory effort and chest wall movement can be visualized to reflect injuries to the ribs and sternum. Deviation of the trachea at the sternal notch may reveal intrathoracic tension on the side opposite the trachea. Distended neck veins indicate cardiac failure, which requires further evaluation. Chest radiography is performed on all significantly injured patients at risk for thoracic injuries. This study can be obtained rapidly in the trauma bay, with the results quickly revealed. The chest radiograph easily identifies the presence of a pneumothorax or hemothorax, as well as rib and sternal fractures. The appearance of the mediastinum may suggest a thoracic aortic injury. An ultrasound of the pericardium is a component of the FAST examination, which may reveal pericardial blood. In recent years, thoracic CT angiography has emerged as a valuable tool in the evaluation of blunt thoracic trauma. CT provides visualization of the chest wall and hemithoraces, allowing determination of rib fractures, pneumothoraces and hemothoraces, and pulmonary contusion. Of great value has been the ability to evaluate the thoracic aorta for injury that historically required standard angiography when suggested by a chest radiograph. Chest CT angiography is able to identify transection of the aortic wall, as well as lower grade injuries that involve only the aortic intima. Many thoracic surgeons have even evolved their technique and proceed with operative intervention based on the chest CT alone, without formal angiography. Some injuries continue to require standard thoracic angiography to characterize anatomy better that is indeterminate on CT imaging.

Penetrating injuries to the chest that cross the mediastinum or are in the vicinity of the heart and mediastinal structures require a methodical evaluation. Penetrating wounds in an area defined by the sternal notch superiorly, the costal margin inferiorly, and the nipples laterally are in this group requiring further evaluation. This includes an assessment of the cardiovascular and aerodigestive structures of the mediastinum. Immediate ultrasound is performed to evaluate the pericardium for effusion. If the pericardium is communicating with one of the hemithoraces, ultrasound may yield false-negative results. Further evaluation has historically included an angiogram of the chest, which has now been replaced by CT angiography in most situations. The heart and great vessels are evaluated for injury, although this can be impeded by the presence of retained missile fragments that cause scatter on CT. Standard angiography can be valuable in this setting. Depending on the trajectory of the penetrating object, the trachea and proximal airways may require evaluation with bronchoscopy. If injury is suspected, the esophagus should be assessed with a combination of esophagoscopy and contrast esophagography. In isolation, these studies have an approximate 20% false-negative rate, although their combined sensitivity approaches 100%. Frequently, thoracic CT will accurately identify the trajectory of the wound and thus guide the need for further evaluation.

Management
Up to 85% of all thoracic injuries can be managed with nothing more than a tube thoracostomy. In most cases, the placement of a chest tube is urgent but may still be performed in a controlled manner that includes strict sterile preparation and excellent surgical technique. This of great importance given the morbidity associated with an empyema that can result from improper chest tube placement. The chest should be prepared appropriately using more than just a splash of povidone-iodine (Betadine) as well as wide draping to maintain the sterility of the field and the tube to be placed. The skin incision should be at the level of the nipple to stay superior enough to avoid the highest reach of the diaphragm. A tunnel is created in a superior direction and the chest is entered bluntly in an interspace above the skin incision. The lung is palpated to confirm chest entry and evaluate for intrathoracic adhesions. A tube large enough to drain blood (typically 32 to 36 Fr) is then advanced superiorly through the incision and posterior to the lung. Chest tubes that are being placed only for a pneumothorax can be positioned in the anterior hemithorax. A valuable maneuver is to spin the tube to confirm that it is not kinked, which would result in poor drainage. The thoracostomy is then connected to an underwater drainage device providing 20 cm H₂O suction.

Tube thoracostomies that drain large amounts of blood on initial placement or demonstrate ongoing output may indicate active intrathoracic bleeding that requires thoracotomy. Typically, immediate thoracotomy is indicated for more than 1500 mL of blood drained on chest tube insertion or more than 300 mL/hr for 3 hours. Although these values clearly may be associated with intrathoracic bleeding, the decision to operate should be carefully considered, especially with regard to the immediate output. Occasionally, chest tubes that initially drain 1500 mL but then have little ongoing output in the setting of hemodynamic stability indicate bleeding from a lung laceration, which ceases with lung reexpansion and may not require or benefit from thoracotomy. Other indications for immediate thoracotomy include a massive air leak with associated pneumothorax or drainage of esophageal or gastric contents from the chest tube. The choice of thoracic approach depends on the presumed injured structures. Access to the lungs, pulmonary vasculature, and hemidiaphragm is through a posterolateral thoracotomy that is best performed through the fifth interspace, with or without removal of the fifth rib. On the right, this incision also exposes the proximal and midesophagus, as well as the trachea and bilateral mainstem bronchi. A left thoracotomy is valuable for approaching the distal esophagus, the left lung, the left ventricle, the descending aorta, and the left subclavian artery. A median sternotomy can be a highly versatile approach, allowing exposure of the right heart, ascending aorta, aortic arch with right-sided arch vessels, and pulmonary vasculature.

Chest Wall and Pleural Space Injuries
Fractures of the ribs are the most common thoracic injury following blunt trauma, with almost 80% of patients with chest injuries sustaining one or more fractures. The chest wall is also commonly involved during penetrating mechanisms, present in 25% of penetrating chest trauma cases. The mortality rate associated with chest wall injuries following blunt trauma is approximately 10%; it exceeds 20% for penetrating injuries. Rib fractures typically occur secondary to compression of the thoracic cage in an anteroposterior or lateral direction that often will dictate the location of the cortical disruption along the rib. Steering wheels and seatbelts are commonly identified as the impinging structure resulting in a fracture. In its most severe form, large amounts of energy transferred to the chest wall can result in the creation of a flail segment, defined as two or more adjacent ribs that are each...
fractured in two or more locations. This results in a separation of a segment of the chest wall. Although pulmonary mechanics can be disrupted in the setting of a flail segment, the greatest physiologic insult is caused by the underlying pulmonary contusion that almost invariably occurs. A pneumothorax occurs with compression of the chest that tears the surface of the lung through a blow-out type mechanism or via laceration from a fractured rib, causing the accumulation of air in the pleural space. Similarly, bleeding from the injured chest wall or lacerated lung can result in a hemothorax as blood accumulates in the pleural space.

During the primary or secondary survey, chest wall injuries are commonly recognized. Chest wall tenderness and changes in chest wall motion are suggestive. Some patients require immediate intervention for chest injuries, but most will subsequently undergo further evaluation. Injuries involving the chest wall or pleural space can frequently be identified on chest radiographs. Figure 18-15 demonstrates a large left pneumothorax on chest radiograph. Chest CT is a common part of the evaluation for thoracic injuries at many centers. CT identifies rib and sternal fractures, as well as pleural air and blood with a great degree of sensitivity. At times, a so-called occult pneumothorax that was not identified on a chest radiograph can be visualized by CT, especially when it only occupies the anterior hemithorax. Figure 18-16 demonstrates a flail segment on chest CT with three-dimensional reconstruction.

Pneumothorax or a large hemothorax on a chest radiograph requires placement of a tube thoracostomy. Chest tube drainage should continue until any pulmonary air leak has resolved and drainage is not excessive. Hemothoraces should be drained if it is thought that the quantity of blood in the pleural space could result in lung entrapment as the hematoma matures. Occasionally, hemothoraces that do not resolve after insertion of a tube thoracostomy benefit from thoracoscopic drainage and tube placement. Patients who demonstrate an occult pneumothorax by chest CT and have no respiratory compromise can be managed with observation and a repeat chest radiograph the following day. Enlargement of the pneumothorax on follow-up imaging necessitates a chest tube. Patients who demonstrate a large amount of subcutaneous air without significant pneumothorax should be followed closely, with a low threshold for placing a chest tube, because a pulmonary air leak may still be present.

Rib fractures can vary greatly in severity, depending on the number present and patient characteristics. Associated pain can be severe and a great concern is the development of respiratory infections. Aggressive analgesia should be provided to allow adequate pulmonary toilet and promote comfort. Adequate analgesia can be achieved with IV narcotics in mild cases but, in more severe cases, patients benefit greatly from the provision of epidural analgesia. Epidural analgesia after chest wall injuries has been associated with fewer ventilator days, shorter intensive care unit length of stay, and fewer hospital days. Furthermore, Bulger and coworkers25 have demonstrated fewer pulmonary infections and decreased duration of mechanical ventilation with the use of epidural analgesia in patients with three or more rib fractures. Nonsteroidal anti-inflammatory drugs (NDAIDs) are also beneficial in conjunction with narcotics. Aggressive pulmonary toilet, including deep breathing, frequent coughing, and incentive spirometry, should be highly encouraged. Chest physical therapy and positive expiratory pressure exercises may also be beneficial. Severe chest wall injuries with pulmonary failure may require mechanical ventilation. There has been renewed interest in the operative fixation of rib fractures, although the optimal indications to perform these procedures and their associated benefit remains incompletely defined. Sternal fractures are managed similar to rib fractures requiring analgesia and pulmonary toilet. Occasionally, sternal fractures result in the
development of a mediastinal hematoma. Although these typically do not require specific treatment, the presence of active bleeding from the adjacent internal mammary artery may require angioembolization or open ligation in the setting of hemodynamic instability.

**Pulmonary Injuries** The lungs are susceptible to injury during blunt and penetrating mechanisms. Although reported in up to 15% of cases in some series, pulmonary contusion after blunt trauma is present in 5.5% of patients in the NTDB. Among patients with blunt chest trauma, pulmonary contusion is common, being identified in 40% of cases. Mortality can be severe, ranging from 10% to 25%, and respiratory failure with the acute respiratory distress syndrome, as well as pneumonia, are frequently encountered. Pulmonary contusion results from energy transfer through the chest wall to the pulmonary parenchyma, resulting in tissue damage, as well as hemorrhage into the alveolar and interstitial spaces. The result is the development of physiologic shunt with hypoxemia. These injuries are also associated with a profound inflammatory response that can lead to further respiratory dysfunction and systemic inflammation. Frequently, pulmonary contusion is identified in the presence of a flail segment and is the major cause of associated morbidity and mortality. Penetrating mechanisms can result in lung contusions or laceration of the pulmonary parenchyma. In one larger multicenter series, 24% of patients with thoracic trauma sustained a penetrating mechanism, of which 2.8% required an urgent thoracotomy for management of pulmonary bleeding. 20

Pulmonary injuries might first be identified on examination or through the drainage of large amounts of blood or air from a tube thoracostomy. Chest radiographs obtained shortly after patient arrival may demonstrate pneumothorax or hemothorax indicative of an underlying pulmonary injury. Lung contusions may be present on the initial chest radiograph but typically require time to become evident on plain film. Pulmonary contusions identified early on chest film are frequently severe and rapidly progressive to respiratory failure. A pulmonary contusion is easily identified by thoracic CT, although at times it can be challenging to differentiate contusion from atelectasis. A basic rule of thumb is that atelectasis does not cross pulmonary fissures, whereas contusions are not limited by ventilatory segments. Also, higher density pulmonary tissue in the vicinity of chest wall injuries, especially when not in dependent areas, is highly suggestive of pulmonary contusion. Figure 18-17 demonstrates a pulmonary contusion on a thoracic CT scan.

Chest tube drainage of large quantities of blood or air may require thoracotomy. The classic guidelines have been described earlier, and the surgeon must make a determination regarding the likelihood of ongoing bleeding that would benefit from operative management. In most cases, tube thoracostomy alone with lung expansion adequately manages low-pressure lung bleeding and small air leaks. Ongoing blood loss indicates a more central, high-pressure source, which should prompt thoracotomy. Bleeding vessels within the parenchyma of the lung should be identified and controlled with suture ligatures. Missile tracts can be opened by passing a GIA stapler through the wound and performing a trachotomy that then exposes injured vessels so they can be controlled. Occasionally, pulmonary resection is required in anatomic or nonanatomic patterns to manage larger segments of injured lung tissue. In the setting of damage control, surgical bleeding can be controlled with sutures or staplers, followed by packing the chest with laparotomy sponges and temporary closure with a sponge and suction dressing. Unlike abdominal packing, the packs should occupy minimal space and be constructed to allow maximal lung expansion.

The management of pulmonary contusion is largely supportive. Patients should be monitored for indications of respiratory decompensation such as hypoxemia, increased work of breathing, and agitation, which mandate intubation and mechanical ventilation. Pulmonary function is supported until the physiologic insult related to the contusion resolves. Efforts to prevent ventilator-associated pneumonia are valuable because of a significantly increased risk. Intubation should be guided by the patient's observed respiratory function and should not be performed prophylactically simply on recognition of pulmonary contusion. Similarly, the presence of a pulmonary contusion or flail chest does not require mandatory chest tube placement in the absence of a pneumothorax or hemothorax. Patients with pulmonary contusion should not be managed with fluid restriction, which is a common misconception. 25 Appropriate resuscitation to maintain acceptable whole-body perfusion should be provided as for other severely injured patients. Excessive volume expansion should be avoided and might benefit from placement of a pulmonary artery catheter to guide fluid administration, especially when significant ventilatory support is required. Aggressive pulmonary toilet can be beneficial, as well as adequate pain control, when concomitant chest wall injuries are present.

**Cardiac Injuries** For obvious reasons, cardiac injuries represent some of the most severe problems experienced by patients after penetrating and blunt trauma. Penetrating injury to the heart occurred in 2% of patients with penetrating trauma in the NTDB and 16% in the subset of penetrating chest trauma alone. These numbers likely underestimate the true incidence of penetrating cardiac injuries because many are immediately lethal and never present to a hospital. In those that do survive to emergency department arrival, the mortality rate is 62%.

![Figure 18-17](image-url) Left pulmonary contusion on thoracic CT. The arrow identifies contused lung, which appears as higher density tissue because of air space hemorrhage and associated edema.
Penetrating cardiac injuries will frequently be evident on initial examination. A significant number of patients will present in extremis with pericardial tamponade or bleeding into one of the hemithoraces. Diagnosis may then be made during resuscitative thoracotomy in agonal patients. In others, indicators of pericardial tamponade may be present, including hypotension with distended neck veins and muffled heart sounds, although their presence can be highly variable. Ultrasound is a valuable tool for quickly assessing the pericardium for fluid and should be performed in all patients with hemodynamic instability. A subxiphoid pericardial window remains the most valuable means of evaluating for cardiac injury and should be used in cases for which ultrasound is not available or the results are inconclusive. A pericardial window allows direct visualization of the pericardial space and can be quickly extended to perform a median sternotomy in the setting of an identified injury.

Cardiac injuries resulting in cardiovascular collapse are approached with a left anterolateral thoracotomy in the emergency department. Injuries that are identified and allow transport to the operating room are best exposed through a median sternotomy. Injuries to the atria can be grasped in a side-biting fashion with a Satinsky clamp and then closed with running or interrupted permanent monofilament sutures. Ventricular injuries can be more challenging and usually are associated with significant bleeding. The laceration can be held closed manually while the defect is closed with horizontal mattress sutures, which are reinforced with pledgets. To gain temporary control, one option is to close the laceration using skin staples; this allows resuscitation and transport to the operating room. Another option is the passage of a Foley catheter through the wound, followed by inflation of the balloon and maintenance of outward tension to occlude the opening until definitive closure can be done.

Blunt cardiac injury resulting in cardiac contusion or more severe structural abnormalities such as septal defects or valvular failure result less frequently, identified in only 3.8% of cases of blunt chest trauma. Most of these represent a contusion of the myocardium that results in arrhythmias and that are frequently self-limiting. In rare cases, blunt cardiac injury results in heart failure, with cardiogenic shock.

The diagnosis of cardiac contusion has been studied extensively but remains somewhat controversial. Although several laboratory and radiographic studies have been found to be associated with cardiac contusion, in practical terms it is only the presence of clinical sequelae that needs to be considered. The presence of an arrhythmia on an electrocardiogram (ECG), most commonly tachyarrhythmias, or cardiogenic shock is the pertinent clinical sequela that requires intervention and therefore is diagnostic in itself. Clinical findings of cardiac contusion that are absent on admission are highly unlikely to develop and, in their continued absence, require no further evaluation. Positive cardiac enzyme levels or radiographic studies have no impact on therapy that is not dictated by clinical and electrocardiographic findings. The presence of hemodynamic instability with evidence of heart failure should prompt an echocardiogram to assess cardiac wall and septal motion, as well as valvular function, which in rare cases can be injured during blunt thoracic trauma.

Blunt cardiac injuries require an ECG at the time of initial evaluation. Patients with mild electrocardiographic changes that do not require treatment should be monitored for 12 hours with telemetry. No further intervention is required if telemetry has revealed no arrhythmias and a follow-up ECG is normal. Those with more severe electrocardiographic changes or arrhythmias on admission require telemetry for 24 to 48 hours and therapy initiated for the specific electrical abnormality. Most patients demonstrate arrhythmias on initial assessment that do not require medical treatment and resolve quickly during the course of monitoring. Heart failure may require treatment with inotropic support and right ventricular afterload reduction, given the frequent involvement of the right heart. Patients who demonstrate structural abnormalities on echocardiography may require urgent operation to repair cardiac injuries.

Thoracic Aortic Injuries

Injuries to the thoracic aorta are also highly severe but fortunately not common. Only 0.3% of patients sustaining blunt trauma in the NTDB sustained an aortic injury, although the associated mortality rate exceeded 47%. As with cardiac injuries, this likely underestimates the true incidence because aortic transection is a common cause of immediate death in blunt trauma patients who never present to the emergency department. In 3.8% of cases, the aorta is involved in penetrating thoracic trauma; almost all these injuries are fatal (mortality = 86.1%). The cause of blunt aortic injuries had traditionally been believed to be a result of rapid deceleration, which tears the aortic wall in the vicinity of the ligamentum arteriosum, where it is fixed to the thorax. Lateral mechanisms may also contribute, during which the aortic arch acts as a lever and causes torque to develop at the aortic isthmus. The result of these mechanisms can range from a tear in the aortic intima to full-thickness transection of the wall. Only patients who experience containment of the rupture by the surrounding mediastinal tissue present to the hospital.

Penetrating aortic injury may be discovered at the time of thoracotomy or sternotomy, often in the setting of patient extremis. Blunt aortic injury may be suggested by a chest radiograph that demonstrates findings such as a widened mediastinum, apical capping, loss of the aortic knob, or deviation of the left mainstem bronchus. Because of a high rate of missed injuries by plain radiograph, most patients involved in high-energy injury mechanisms undergo helical CT angiography of the chest to evaluate for aortic injury. Injuries to the thoracic aorta can be identified on CT as a disruption in the intima or as a pseudoaneurysm with a mediastinal hematoma, which appears as contrast contained outside the aortic lumen. Usually, this study alone is sufficient to plan operative repair, although standard angiography is necessary in some cases, usually at the discretion of the thoracic surgeon. A contained pseudoaneurysm from an aortic transection is depicted on a chest CT scan in Figure 18-18.

Patients who present with a blunt thoracic aortic rupture that is contained will require operative repair. The natural history of these injuries is slow expansion, which ultimately culminates with free aortic rupture. It has been recognized that there is usually a delay in this progression that allows other more urgent issues, such as acute hemorrhage, to be addressed. In the interim, medical therapy with beta antagonists aimed at controlling aortic wall stress is absolutely essential and should be instituted early. Open surgical therapy to repair the aorta is accomplished through a left thoracotomy. Small penetrating injuries to the aorta can be closed primarily if exposed prior to exsanguination. Larger penetrating injuries
and blunt transection require replacement of a segment of the aorta with a prosthetic graft. This is most commonly performed with the assistance of cardiopulmonary bypass, with full bypass through a femoral-femoral approach or with a centrifugal pump and left heart bypass. The use of cardiopulmonary bypass has been associated with a decreased incidence of paraplegia, which can result from cessation of aortic blood flow during the clamp and sew technique. Proximal and distal aortic control, as well as control of the left subclavian artery, are achieved and the injured segment replaced. This occasionally requires reimplantation of the left subclavian artery, depending on the proximal extent of the injury.

More recently, there has been a great deal of interest in the use of endovascular stent grafts to repair the injured thoracic aorta. This is particularly appealing for those patients at high operative risk and with favorable vascular anatomy, but further study is required to establish the role of this modality confidently. In many centers, this approach is becoming a mainstay of treatment for managing these injuries. Described advantages associated with the endovascular repair of aortic injury include a reduction in the incidence of paraplegia and a potential improvement in mortality. Although rare, patients with an intimal tear only may be candidates for nonoperative management because many of these injuries will heal without intervention. Patients should be treated with beta blocker therapy and undergo follow-up imaging to ensure the absence of expansion and ultimately the resolution of the injury.

Tracheobronchial Injuries Injuries to the tracheobronchial tree are uncommon but are associated with significant morbidity and mortality. In the NTDB, there are a total of only 275 tracheobronchial injuries, representing 0.02% of all patients injured by a blunt mechanism and 0.05% of all patients injured by a penetrating mechanism. Based on a literature survey, Kiser and colleagues have reported on 265 blunt tracheobronchial injuries from a period of 123 years, in which 59% were caused by MVAs. The mortality from these injuries since 1970 was only 9% but it is believed that many patients with these injuries succumb prior to the arrival of prehospital personnel. Approximately 50% of these injuries involved the right mainstem bronchus within 2 cm of the carina. It is though that these injuries result from the application of a large amount of energy to the anterior chest, which pulls the lungs laterally and avulses the bronchi from the fixed carina. Another proposed mechanism is a rupture caused by rapid compression of the lungs and airways against a closed glottis, which perforates the trachea along the membranous portion. Penetrating injuries, mainly secondary to gunshot wounds, can also result in injuries to the tracheobronchial tree.

Identification of tracheobronchial injuries depends somewhat on the location of airway disruption. Significant subcutaneous air may be present on physical examination. Injuries that involve the thoracic trachea and proximal bronchi may result in large amounts of pneumomediastinum identified by chest radiography or chest CT. More distal airway injuries will typically cause a pneumothorax requiring insertion of a tube thoracostomy. A continuous air leak with persistent pneumothorax is highly suggestive of an injury to a bronchus or large bronchiole. Diagnosis is made with bronchoscopy, which most commonly is performed with a flexible bronchoscope because the use of a rigid bronchoscope requires neck extension, which is usually not feasible prior to excluding a cervical spine injury. Bronchoscopy allows for the identification of the injury and a detailed characterization, such as the location and severity of the disruption.

Initial management of tracheobronchial injuries includes careful airway management. With the placement of any airway, avoiding any further disruption is vital and may benefit from bronchoscopic guidance under direct visualization. Injuries that occupy less than one third of the luminal circumference may be considered for nonoperative management if any pneumothorax and associated air leak that were present resolve after insertion of a chest tube and the lung expands completely. Management includes antibiotics, humidified oxygen, careful suctioning, and close observation to be sure that infectious sequelae do not develop. Operative management of the trachea, right-sided airways, and proximal left mainstem bronchus is best approached through a right posterolateral thoracotomy. Distal left-sided injuries are repaired through a left thoracotomy. A vascularized intercostal muscle flap should be mobilized and preserved on opening the chest because placement of a retractor will prevent harvest of this potential tissue coverage. Repair includes débridement of devitalized tissue or segmental resection with closure, using absorbable sutures. The repair then benefits from coverage with a tissue pedicle, such as a previously preserved intercostal muscle flap. Patients requiring ongoing ventilation may benefit from passage of the endotracheal tube distal to the repair to provide protection. Other options include dual-lung ventilation and extracorporeal life support during the immediate postoperative time period.

Esophageal Injuries Injuries to the thoracic esophagus occur predominantly after penetrating trauma but remain uncommon by any cause. Only 2% of all patients in the NTDB with penetrating chest trauma sustained an injury to the esophagus. Most of these are caused by gunshot wounds, followed by stab wounds in fewer than 20% of cases. The mortality associated with these
injuries is significant (39%) because of the severe nature of esophageal perforation and because the adjacent vital structures can also be injured along with the esophagus. Blunt esophageal injury is exceedingly rare, identified in only 0.02% of blunt trauma patients in the NTDB. Of these patients, 25% die because of the significant energy required to rupture the thoracic esophagus. Blunt esophageal injury is believed to be caused by a rapid elevation in intraluminal pressure during compression of the chest or abdomen. An impact to the upper abdomen can compress the distended stomach, leading to transmission of air and fluid up the esophagus and resulting in a perforation of the wall, usually in the distal segment.

Penetrating esophageal injuries may be suggested by the trajectory of a missile or weapon. Injuries in the vicinity of the mediastinum require consideration of possible esophageal injury. The esophagus is best evaluated through a combination of contrast esophagography and esophagoscopy. The combination of these two modalities results in a sensitivity of almost 100% for esophageal injury. Findings include extravasation of contrast from the esophageal lumen or a disruption of the mucosa visualized on endoscopy. These studies should also be used to determine the location of the injury along the esophagus to assist in operative planning. Blunt trauma patients may demonstrate large amounts of pneumomediastinum, which prompts a further workup with esophagography and esophagoscopy. Chest CT may reveal air adjacent to the esophagus but outside the lumen, as well as surrounding soft tissue inflammation. At times, the defect itself can be visualized on CT. Esophageal injuries at the gastroesophageal junction may result in abdominal pain and tenderness.

The rapid identification and management of esophageal injuries are paramount because delays are associated with worse outcomes. Clinical evaluation and studies that reveal an esophageal injury should prompt immediate operative repair. The upper and midthoracic esophagus are best approached through a right posterolateral thoracotomy through the fourth or fifth interspace, whereas the lower esophagus is exposed from the left through the sixth or seventh interspace. Contrast studies that demonstrate the injury within the abdomen benefit from a laparotomy to repair the esophagus from an abdominal approach. Again, maintenance of a vascularized intercostal muscle flap is of great value for coverage of the repair. The injury should be entirely exposed, which usually requires opening the muscular layer superiorly and inferiorly to reveal the extent of the mucosal defect, which is commonly larger than the muscular disruption. The esophagus is then closed in one or two layers, frequently using an absorbable mucosal suture followed by interrupted muscular sutures using a permanent material. The repair is covered with the muscle flap or another adjacent tissue to provide protection, given the high rate of leak and fistula formation. Esophageal repairs at the gastroesophageal junction can be covered with a fundoplication of gastric tissue. Chest and mediastinal drains should be placed in the vicinity of the repair to control any leak that may develop. A gastrostomy and feeding jejunostomy are frequently advisable to allow gastric decompression and early nutritional support. Esophageal injuries that are identified late may not allow primary repair because of the massive amounts of inflammation that can develop. In some situations, esophagectomy is the only option to allow recovery from the associated inflammatory insult, followed by planned elective reconstruction, when feasible.

Diaphragmatic Injuries Injuries to the diaphragm can be a diagnostic challenge. They are often first identified at the time of laparotomy for penetrating injury or late following blunt trauma. Approximately 3% of patients with trauma to the torso have a diaphragmatic injury identified, with approximately two thirds of them secondary to penetrating trauma. In the NTDB, 26.6% of penetrating chest injuries included a diaphragmatic injury, which was associated with a 22.5% mortality. This is secondary to injuries involving adjacent vital organs because diaphragmatic injuries themselves are usually of limited threat to life. Blunt diaphragmatic injuries occur in only 1.8% of blunt thoracic injuries and are believed to be a result of a rapid increase in intra-abdominal pressure during an anterior impact that causes a blowout of the diaphragmatic tissue. Injuries are most commonly recognized on the left side, with only 25% occurring adjacent to the liver or in the central portion of the diaphragm. Because of the high energy required to create a blunt diaphragmatic rupture, there is a significant associated mortality, approximately 29%. The morbidity related to diaphragmatic injuries is occasionally identified months to years later when the perforation was not initially recognized and repaired. The natural history of these injuries includes progressive enlargement with herniation of abdominal viscera into the chest, which is commonly the identified abnormality on radiographic evaluation.

Diagnosis requires a high index of suspicion when confronted with even the most subtle indicators of injury to the diaphragm. Frequently, penetrating diaphragmatic injuries are discovered on operative exploration of the chest or abdomen. Identifying the trajectory of the injury will usually allow recognition of the diaphragmatic defect. Blunt injuries can be more elusive. The chest radiograph may identify injuries to the diaphragm by demonstrating the presence of abdominal viscera, most commonly the stomach, within the chest, although this finding may be absent in a significant number of injuries. Figure 18-19 illustrates a left diaphragmatic injury on a plain chest radiograph. Passage of a nasogastric tube can be of assistance if
the tube is identified in the lower left hemithorax; the administration of gastric contrast may add to the detection. Chest and abdominal CT scans may demonstrate the presence of abdominal visceral in the chest or an abnormality of the diaphragm itself, such as discontinuity, thickening, or elevation. At times, three-dimensional reconstruction of the CT developed from newer generation scanners can demonstrate the diaphragmatic defect with high sensitivity. Given the challenge of diagnosis, operative exploration may be required when imaging is suggestive. In patients who have no other indication for laparotomy, video-assisted thoracoscopy or cautious laparoscopy conducted to avoid tension pneumothorax may offer less invasive means to visualize the diaphragm.

Repair of diaphragmatic injuries includes debridement of nonviable tissue and closure of the defect. Typically, the diaphragm exhibits enough redundancy to close all but the largest defects primarily. Closure is commonly performed with a nonabsorbable suture in a single layer, incorporating large full-thickness bites of healthy diaphragmatic tissue. Hemostasis in this layer is important because branches of the phrenic artery may be exposed at the edges of the tear. When the repair involves mostly muscle, horizontal mattress sutures may reinforce the suture line. Large areas of tissue loss are rare in traumatic rupture but, when present, may require reconstruction with a prosthetic. Nonabsorbable synthetic materials are reasonable in noncontaminated fields although they should not be placed when the GI tract has been injured. When the diaphragm has been traumatically detached from the periphery, it may be reinserted to the chest wall one or two interspaces superior.

Injuries to the Abdomen
Abdominal injuries are frequently encountered in the management of trauma patients. Of all patients in the 2009 NTDB, 13% sustained abdominal injuries, associated with an overall mortality rate of 7.7%. During the evaluation of the injured patient, the abdomen is of high priority because the vital nature of the contained organs and structures. Blunt trauma can result in the laceration of solid organs usually causing bleeding, which in its most severe form manifests as hemorrhagic shock or as visceral perforation of the GI tract. Penetrating trauma to the abdomen can result in laceration of solid organs and perforation of hollow organs, which must be discovered and repaired at the time of laparotomy.

Immediate Management
Immediate management of abdominal injuries consists of resuscitation and evaluation (see earlier). Patients in shock require initiation of resuscitation with crystalloid solutions and blood products, as well as a rapid assessment for the source of bleeding. Retained foreign bodies traversing the abdominal wall should be maintained throughout the initial evaluation and protected from excessive movement. These should then be removed only after defining a definitive plan, which almost always includes abdominal operation.

Blunt Abdominal Trauma Evaluation
Patients who present with blunt versus penetrating mechanisms of injury frequently require varying approaches to evaluation. Blunt trauma patients who are unstable and have intra-abdominal fluid identified on FAST require an emergent laparotomy to manage bleeding. Surgeons can quickly become skilled at performing the FAST examination and should be actively involved in obtaining and interpreting the study. If FAST is unavailable, aspiration of 10 mL or more of gross blood on DPL also suggests an intra-abdominal source of hemorrhage requiring emergent operation. Furthermore, patients with peritonitis require abdominal exploration to evaluate for hollow visceral injury. Other patients will undergo further workup of the abdomen to evaluate for intra-abdominal injury. Figure 18-20 presents an approach to evaluating the blunt trauma patient with possible abdominal injury.

Abdominal CT has become the mainstay of imaging for the stable blunt trauma patient and has led to the emergence of nonoperative management of many solid abdominal organ injuries. Abdominal CT is typically performed with IV contrast timed to capture the portal venous phase, which best demonstrates the vasculature and visceral perfusion of the solid abdominal organs. CT provides excellent visualization of the solid organs, allowing the characterization of injury severity (injury grade) and the recognition of active bleeding, which appears as contrast extravasation. Imaging findings assist in making management decisions regarding the need for operative, nonoperative, or angiographic therapy. The retroperitoneal structures are also well visualized on CT, identifying injuries that are difficult to evaluate with FAST or DPL. DPL demonstrating more than 100,000 red blood cells/mm³ is indicative of intra-abdominal injury and historically mandated a laparotomy. The high nontherapeutic laparotomy rate associated with this practice has led to the nonoperative principles commonly used today because a large percentage of abdominal structures that had bled were no longer bleeding at the time of abdominal exploration. The frequent lack of bleeding at laparotomy suggested that the patient’s physiologic condition was more important than the presence of intra-abdominal blood when making treatment decisions.

Abdominal CT is less sensitive for detecting hollow visceral injury, although this has improved as imaging technology has progressed from the older 4- and 16-slice CT scanners to the newer 64- and 128-channel machines. Hollow viscous injury is suggested by the recognition of bowel wall thickening, inflammation in the surrounding adipose tissue seen as stranding, or presence of free intraperitoneal fluid. Administration of oral contrast is not necessary and might increase the risk of vomiting with aspiration. It is paramount that the presence of unexplained free fluid on imaging be carefully evaluated and a high index of suspicion for bowel injury be maintained. Frequently, a combination of these radiographic findings, with clinical signs and symptoms such as an abdominal seatbelt mark or tenderness on examination, are suggestive and may require exploration. A challenging scenario is the identification of intra-abdominal fluid on imaging without the presence of solid organ injury to explain its presence. In a significant percentage of cases, this fluid represents blood from a mesenteric tear that is no longer bleeding, but being confident that a bowel injury is not present can be difficult. The amount of fluid identified may be helpful, with fluid visualized in more than one abdominal quadrant suggestive of a bowel injury requiring laparotomy. In many cases, patients can provide an adequate abdominal examination to follow for symptoms indicative of a hollow viscous injury. In patients for whom mental status or concomitant injuries compromise the abdominal examination, DPL may provide valuable information. Findings on lavage fluid evaluation, including more than 500 white blood cells/mm³, amylase, bilirubin, or particulate
matter, have been found to be indicative of a hollow visceral injury.

**Penetrating Abdominal Trauma Evaluation**

Penetrating abdominal trauma is typically evaluated differently than blunt mechanisms. Because of the high rate of intra-abdominal injury, patients sustaining anterior abdominal gunshot wounds are frequently transferred quickly to the operating room for laparotomy. Depending on the location of the penetrating wound, the chest may require evaluation for mediastinal, pleural, or pulmonary injuries. It may be valuable to attempt to determine the trajectory of the missiles while preparing for surgery because this may assist in directing the exploration. Penetrating wounds of the skin should be identified with radiopaque markers and plain radiographs obtained to determine their location and relation to missile position. The number of missiles and skin wounds should add up to an even number, or a more intense search for injuries is required. This evaluation should be brief and not delay operation, especially in the hemodynamically unstable patient.

Abdominal stab wounds can be managed somewhat differently. Figure 18-21 presents one approach that was recently developed after a multicenter trial facilitated by the Western Trauma Association. Patients with hemodynamic instability, peritonitis, or evisceration require immediate laparotomy with repair of injuries. Others can have the penetrating wound explored locally to determine whether the anterior or posterior abdominal fascia was violated. Those without fascial penetration can be discharged to home. In the setting of a positive or equivocal local wound exploration, patients should be monitored with serial abdominal examinations and determinations of hemoglobin levels every 8 hours. Throughout this evaluation, the development of peritonitis, hemodynamic instability, significant decreases in hemoglobin level, or development of leukocytosis should prompt further evaluation, usually with laparotomy. Patients without clinical change after 24 hours can have a diet instituted and be discharged to home. Others believe that penetration of the abdominal fascia warrants exploration to identify any possible injury immediately, with the understanding that this will result in a higher nontherapeutic laparotomy rate.

An additional tool that has been used more recently is laparoscopy, mainly to establish or exclude the presence of peritoneal penetration. It remains fairly well accepted that laparoscopy in most hands is not sufficient to explore the entire abdomen but it can be used to identify violation of the parietal peritoneum, which can then prompt laparotomy to

**FIGURE 18-20** Algorithm for the evaluation and management of blunt abdominal trauma.
address injuries. Patients without peritoneal penetration can be discharged to home after recovery from anesthesia in the absence of other injury or illness.

Penetrating wounds from both high- and low-energy mechanisms that occur posterior to the midaxillary lines and throughout the back may benefit from three-dimensional imaging with CT. Patients with abdominal symptoms or a track that clearly enters the abdomen require abdominal exploration. Otherwise, the thickness and density of the retroperitoneum often result in penetrating injuries avoiding significant structures, therefore requiring no operative intervention. CT can often determine the track of the penetrating injury by lining up external markers with internal missiles and locules of air within the tissues. Establishment of the injury track often allows decisions to be made regarding further evaluation or necessary injury management. Information regarding vertebral column, spinal cord, pelvic, and vascular injuries within the retroperitoneum can also be obtained by CT. Injury tracks identified by CT that are within close proximity to intra-abdominal organs typically require abdominal exploration. One limitation of this approach is the presence of radiographic scatter caused by retained missiles, which may obscure findings on CT scans.

Management

Patients who require laparotomy should undergo a systematic exploration so that all areas of the abdomen are assessed and injuries are not missed. As noted earlier, this approach may require abbreviation in the setting of deteriorating physiologic condition. As a standard technique, the abdomen is opened from the xiphoid process to pubic symphysis to provide adequate exposure of all abdominal structures. The falciform ligament is divided, separating the liver from the abdominal wall to improve retraction and perihepatic packing. Using a hand-held retractor, blood is quickly evacuated from all four quadrants of the abdomen and laparotomy sponges are placed to provide temporary hemostasis. Many surgeons then prefer to place a fixed retractor to provide necessary exposure. Packed sponges are removed to address bleeding structures and hemostasis is achieved, or the packs are replaced in the damage control setting. The entire GI tract is carefully evaluated, from the gastroesophageal junction to the rectum at the peritoneal reflection. This includes entering the lesser sac to evaluate the posterior stomach and the pancreas. Areas stained with blood that are of concern for injury should be explored further with careful dissection. The required management of specific injuries is detailed later. Developing physiologic compromise should be promptly recognized; this requires open lines of communication with anesthesia providers throughout the operation. In this setting, the operation should be abbreviated, with the only goals becoming hemorrhage and contamination control with temporary abdominal closure. Otherwise, the abdominal fascia can be closed in a single layer and the subcutaneous wound addressed as dictated by the level of intra-abdominal contamination.

Splenic Injuries

The spleen is the most commonly injured abdominal organ in the NTDB, with 3.2% of all injured patients and 50.7% of patients with blunt abdominal trauma demonstrating splenic injuries. This is similar to a large multicenter series that included data from 1993 to 1997 in which 2.6% of injured patients sustained splenic trauma. The ability to manage splenic injuries is required for anyone who definitively treats patients with blunt abdominal trauma. A significant mortality of 10.8% is associated with blunt splenic injury among centers who contribute to the NTDB. Many of these deaths are caused by associated injuries and prehospital delays; it would be hoped that few patients should succumb to an injury that can be rapidly addressed. The pathophysiologic function of blunt splenic injury can include direct compression of the organ in the left upper quadrant of the abdomen or a deceleration mechanism that tears the splenic capsule or parenchyma, mainly at areas fixed or tethered to the retroperitoneum. A subcapsular hematoma of the spleen is demonstrated in Figure 18-22 at the time of splenectomy. Bleeding from a ruptured spleen can be ongoing at the time of presentation or frequently will have stopped. This cessation of bleeding allows many of these injuries to be managed without splenectomy, although reinitiation of bleeding from a splenic injury can be delayed. This is of obvious concern for patients who undergo nonoperative management and many studies have been devoted to identifying which patient populations are at greatest risk of delayed hemorrhage. The rate of late bleeding was determined to be 10.6% in a large series, although

![Figure 18-21 Algorithm for the evaluation and management of anterior abdominal stab wounds. (Adapted from Biffi WL, Kaups KL, Cothren CC, et al: Management of patients with anterior abdominal stab wounds: A Western Trauma Association multicenter trial. J Trauma 66:1294–1301, 2009.)](image-url)
this rate varies greatly with the grade of splenic injury.\textsuperscript{32} Penetrating splenic trauma is less common but is still present in 14.5\% of all penetrating abdominal injuries in the NTDB. This is somewhat higher than reported in a large series from Grady Memorial and Ben Taub General Hospitals during the 1980s and 1990s, in which 9.2\% and 7.6\%, respectively, of penetrating abdominal injuries involved the spleen.\textsuperscript{35}

Identification of splenic injuries may occur during laparotomy in patients who are unstable and taken emergently to the operating room. As noted, unstable patients with intra-abdominal fluid on FAST require exploration, with the spleen commonly being the bleeding intra-abdominal organ. In stable patients, abdominal CT performed with IV contrast is the mainstay for diagnosing and characterizing splenic injuries. Images are typically obtained with the contrast in the portal venous phase to enhance the splenic parenchyma maximally while still being able to visualize the vasculature. Splenic injuries appear as disruptions in the normal splenic parenchyma, frequently with surrounding hematoma and free intra-abdominal blood. Occasionally, active extravasation of contrast, identified as a high-density blush, can be identified, contained within a pseudoaneurysm or bleeding into the peritoneal space. Figure 18-23 illustrates a splenic injury with active extravasation on an abdominal CT scan. Other findings can include a hematoma confined to the subcapsular space or even complete devascularization of the organ caused by injury of the hilar vessels. Table 18-5 demonstrates the AAST Organ Injury Scaling system of grading spleen injuries by anatomic characteristics. Spleen injury grading relies on describing parenchymal or subcapsular characteristics and the presence of vascular involvement.

A more recent advance in the management of splenic injury has been the use of angiography to evaluate further and, at times, treat these injuries. Usually, this modality has been used for injuries that demonstrate active extravasation by CT, although a well-defined indication for these studies is still being elucidated. Some centers have a lower threshold for angiography and use it in the setting of all high-grade injuries because of the greater risk of delayed bleeding during nonoperative management. Angiography can identify specific sites of bleeding from the splenic parenchyma and underlying segmental or trabecular vessels; however, it cannot characterize the splenic parenchymal injury but can be complementary to CT. One major benefit of angiography is the potential to obstruct sites of bleeding endovascularly using angioembolization. Patients who are candidates for nonoperative management of their splenic injury but demonstrate a blush by CT, indicating active extravasation, may benefit from angiography with embolization to eliminate the splenic pseudoaneurysm. There is evidence suggesting that this intervention may increase the rate of splenic injuries that can be safely managed nonoperatively.\textsuperscript{34} Despite this, only patients not in shock who demonstrate hemodynamically stability should be considered for angiographic evaluation and possible angioembolic treatment. With appropriate patient selection, many patients with blunt splenic trauma can be managed without splenectomy. The value of careful patient selection for nonoperative management cannot be overstated. It should not be overlooked that a definitive treatment for splenic bleeding exists in splenectomy, which does not have an overly great risk profile, especially in comparison to the adverse implications of ongoing hemorrhage. Therefore, no bleeding patient should go without splenectomy or splenic repair, especially in an attempt to push the figurative nonoperative envelope. Nevertheless, there are many patients who, at presentation, are no longer bleeding from a splenic injury and do benefit from avoiding an unnecessary operation. Fortunately, based on the patient’s physiology, it is usually possible to elucidate those that have a hemostatic splenic injury and are appropriate candidates for nonoperative management. Another important point is that nonoperative management does not mean lack of intervention or care provided. Nonoperative management of splenic injury, done properly, is much more labor-intensive than operative therapy and requires greater resources over a longer period. Having the infrastructure in place is mandatory to provide the ongoing surveillance required to manage a spleen injury without surgery. To be a candidate for nonoperative management, there can be no physiologic indication of ongoing bleeding. Therefore, hemodynamic stability is a prerequisite and must be present without
ongoing intravascular volume support. Hemodynamic stability is indicated by a normal blood pressure and lack of tachycardia, no physical examination findings indicating shock, and absence of metabolic acidosis. The initial hemoglobin level may not be reflective of actual blood loss until intravascular equilibration occurs. Patients who have experienced transient hemodynamic instability that responded to crystalloid infusion may be considered but a lower threshold for operation should be maintained.

Although the patient’s physiologic condition is the most important factor when considering nonoperative management, there are other factors that may have an impact on this decision. Some controversy exists about whether older patients are at greater risk of failing nonoperative management. Two retrospective studies have compared failure rates between groups older and younger than 55 years of age and reached opposite conclusions.35,36 The larger of these studies demonstrated a significantly greater rate (19% versus 10%) of failure of nonoperative management in patients older than 55 years.36 Despite this, over 80% of older patients who underwent attempted nonoperative management still succeeded, so most would agree that age alone is not a contraindication to management without surgery, but that these patients require a greater degree of scrutiny. Another consideration that may affect decision making is the grade of splenic injury identified on imaging at admission. There are no prospective data to provide guidelines so this also has created a great deal of controversy. One multi-institutional retrospective study conducted by EAST identified failure rates of 33.3% in grade IV and 75% of grade V injuries, with 8% of failures occurring more than 9 days after injury.35 Another multicenter study had few of these high-grade injuries but all of them failed nonoperative management.35 Varying conclusions have resulted from these data. Some believe that failure rates after high-grade splenic injuries are unacceptably high, especially given that almost one in ten may occur after hospital discharge and that splenectomy does not carry a markedly high morbidity. Others think that a significant number can still be managed nonoperatively, despite the higher failure rate. The result is that this decision remains personal preference and is often guided by surgical intuition. Our preference is to reserve nonoperative management for grades I and II injuries, as well as grade III injuries that are isolated.

Operative management of splenic trauma may be in the setting of instability at admission, when the exact location of bleeding is unknown or after failed nonoperative management, when the spleen is suspected to be the culprit preoperatively. In either setting, the best approach is through a midline incision with packing of all four quadrants when instability is present. A fixed retractor facilitates exposure of the left upper quadrant. Splenectomy begins with division of the peritoneum laterally, which is facilitated by retracting the spleen posteromedially to expose these attachments. The dissection begins at the splenocolic ligament by dividing the peritoneum at the white line of Toldt and then continuing superiorly until the short gastric vessels are encountered. After the peritoneum is taken down, a blunt plane is created posterior to the spleen in a medial direction, extending behind the tail of the pancreas. This maneuver mobilizes the entire spleen and distal pancreas, which allows the spleen to be delivered into the visualized wound. The short gastric vessels are then identified and ligated, with care taken to avoid injuring the greater curve of the stomach. All that remains are the hilar vessels, which are clamped and ligated, being sure not to involve the tail of the pancreas in this dissection. Drains should not be placed unless there is concern that the tail of the pancreas was also injured. Postsplenectomy vaccines must be provided to ensure protection from encapsulated bacteria, including Strep tococcus pneumoniae, Neisseria meningitidis, and Haemophilus influenzae. Several splenic salvage options exist, although these are becoming less commonly used because more patients who would commonly benefit from these techniques are managed nonoperatively. Splenic injury secondary to penetrating abdominal trauma is usually identified during laparotomy and should be addressed based on the presence or absence of ongoing bleeding. In the setting of damage control, the splenic injury can be packed but, more commonly, splenectomy is performed because of the rapidity at which the spleen can be removed and managed definitively.

**Hepatic Injuries** Second only to the spleen, injury to the liver is extremely common after blunt abdominal trauma. Overall, liver injuries occurred in 2.9% of all patients included in the NTDB, with 39.8% of those with blunt abdominal trauma sustaining injury to the liver. The mortality associated with these blunt hepatic injuries was 14.9%. Richardson and associates38 have reported on their 25-year experience with hepatic trauma, during which the incidence of major liver injuries remained stable, ranging from 12% to 15%. Mechanisms of blunt hepatic trauma include compression with direct parenchymal damage and shearing forces, which tear hepatic tissue and disrupt vascular and ligamentous attachments. The liver is partially
protected by the thoracic cage, although even the rigid ribs provide little support during high-energy mechanisms. Liver injury secondary to penetrating abdominal trauma is also common, given the sizable volume occupied by the liver in the abdomen. Nicholas and coworkers have described the presence of liver injury in 34.4% of cases of penetrating abdominal trauma, which was similar to a comparison group that demonstrated an incidence of 29.3%. In the NTDB, the liver is the most commonly injured abdominal organ after penetrating trauma, present in 42.3% of cases. An associated mortality of 19.1% demonstrates the danger of these injuries. Penetrating mechanisms can cause variable degrees of tissue destruction, depending on the associated energy of the missile. Furthermore, penetrating injuries can cause significantly greater morbidity when vascular or biliary tree structures are involved.

As with splenic injuries, liver injuries are often first diagnosed on entering the abdomen in the unstable patient explored for the finding of free fluid on FAST examination. Stable patients with suspected hepatic trauma should undergo abdominal CT with IV contrast. Current CT modalities are excellent at providing significant anatomic detail that allows highly accurate characterization of injuries. Findings on CT associated with liver injury include disruption of the hepatic parenchyma with perihepatic blood or hematoma, as well as hemoperitoneum. Occasionally, contrast extravasation visualized as a high-density blush is identified indicating the presence of a pseudoaneurysm or active bleeding external to the liver capsule. Figure 18-24 demonstrates a CT scan of a grade III liver laceration with extravasation of contrast. Findings on CT can be used to characterize the injury according to the AAST Organ Injury Scale for liver injuries. Liver injury grading involves the extent of parenchymal involvement and presence of vascular injury (Table 18-6).

Patients who are unstable during emergency department evaluation and are found to have intra-abdominal fluid require immediate laparotomy. Despite all that has evolved in the management of liver injuries, it should not be overlooked that unstable patients require operative management of bleeding. Patients who are stable benefit from a more conservative approach. As with spleen injuries, most injuries to the liver have stopped bleeding by the time of evaluation, which is usually reflected by the patient’s physiologic condition. Hemostatic injuries benefit little from operative intervention but instead require close surveillance for indicators of rebleeding or associated complications. This approach has been shown to achieve excellent results in multiple series, with successful nonoperative management in 85% to 97% of cases. Despite avoiding unnecessary operation in a significant number of patients, the application of a nonoperative approach for select patients has actually resulted in a decrease in mortality for liver injuries, despite an increase in overall injury severity over the last 3 decades. To qualify for attempted nonoperative management, patients must demonstrate evidence that hepatic bleeding has stopped. This is typically indicated by the absence of tachycardia, hypotension, metabolic acidosis, and physical examination evidence of shock, being sure that the patient is not receiving ongoing fluid resuscitation that might mask cardiovascular compromise. Even more than in the setting of splenic injuries, physiologic stability is the major predictor of successful nonoperative management of hepatic trauma. This is true independently of injury severity, in that even high-grade liver injuries should be considered for nonoperative management as long as the patient remains hemodynamically stable, without evidence of bleeding.

![Figure 18-24](image)

**FIGURE 18-24** Grade 4 liver laceration involving the right hepatic lobe on abdominal CT scan. Note the focus of active contrast extravasation within the injured liver parenchyma at the periphery of the injury (arrow).

<table>
<thead>
<tr>
<th>INJURY GRADE</th>
<th>INJURY TYPE</th>
<th>DESCRIPTION OF INJURY</th>
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<tbody>
<tr>
<td>I</td>
<td>Laceration</td>
<td>Subcapsular tear &lt;10% surface area; intraparenchymal depth</td>
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<tr>
<td></td>
<td>Laceration</td>
<td>Capsular tear &lt;1 cm parenchymal depth</td>
</tr>
<tr>
<td>II</td>
<td>Laceration</td>
<td>Subcapsular tear, 10% to 50% surface area; intraparenchymal &lt;10 cm in diameter</td>
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<tr>
<td></td>
<td>Laceration</td>
<td>Capsular tear, 1-3 cm parenchymal depth, &lt;10 cm in length</td>
</tr>
<tr>
<td>III</td>
<td>Laceration</td>
<td>Subcapsular tear &gt;50% surface area of ruptured subcapsular or parenchymal hematoma; intraparenchymal hematoma &gt;10 cm or expanding</td>
</tr>
<tr>
<td></td>
<td>Laceration</td>
<td>&gt;3 cm parenchymal depth</td>
</tr>
<tr>
<td>IV</td>
<td>Laceration</td>
<td>Parenchymal disruption involving 25%-75% hepatic lobe or one to three Couinaud segments</td>
</tr>
<tr>
<td>V</td>
<td>Laceration</td>
<td>Parenchymal disruption involving &gt;75% of hepatic lobe or more than one Couinaud segment within a single lobe</td>
</tr>
<tr>
<td></td>
<td>Vascular</td>
<td>Juxtahepatic venous injuries (e.g., retrohepatic vena cava, central major hepatic veins)</td>
</tr>
<tr>
<td>VI</td>
<td>Vascular</td>
<td>Hepatic avulsion</td>
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</table>
In contradistinction to spleen injuries, the operative intervention for liver trauma is less definitive and can be challenging. Therefore, hemodynamic decline requires operation but slow decreases in hemoglobin levels are at times tolerated and even occasionally treated with transfusion. This is especially true when there are other injuries that may account for some blood loss, and the decline in hemoglobin level may not be reflective of ongoing hepatic bleeding. Because many liver injuries are associated with some degree of hemoperitoneum, it is possible that a hollow visceral injury could be present but overlooked if the intra-abdominal fluid is attributed solely to the liver injury. Therefore, serial abdominal examinations to detect evidence of intestinal injury are an important part of nonoperative management of any solid abdominal organ.

In some cases, CT reveals a liver injury that demonstrates the extravasation of IV contrast from a disrupted vascular structure. These appear as a blush of high-density contrast, often within the injured-appearing hepatic parenchyma. In the setting of hemodynamic stability, this extravasation is usually contained within a pseudoaneurysm. The natural history of hepatic pseudoaneurysms is not exactly known but it is believed that they may be associated with an increased risk of delayed bleeding, especially when caused by hepatic arterial branches. A more recent advance in the management of hepatic pseudoaneurysms is the use of hepatic angiography, with embolization of blood vessels that demonstrate extravasation. Even with successful embolization, patients need standard surveillance, which is required for all hepatic injuries managed nonoperatively. When selected appropriately, the use of angioembolization has improved the rate of successful nonoperative management by reducing the number of conversions to operative therapy.\(^n=41,42\) This has also allowed many higher grade injuries that historically might have required operation to be managed without surgery.

The evolution of nonoperative approaches to liver trauma has required advances in evaluating and managing complications that arise. In addition to delayed rebleeding, these include bile leaks with biloma formation, hemobilia, and development of liver abscesses. Frequently, these are suggested by the development of abdominal symptoms, with or without evidence of systemic infection or inflammation. CT \(or\), at times, ultrasound will identify the liver injury—related pathology. Percutaneous drainage guided by CT or ultrasound is usually successful in managing abscess or biloma. Endoscopic retrograde cholangiopancreatography (ERCP) with stent placement is occasionally required to decompress the biliary tree and promote healing of a bile leak. Occasionally, a laparoscopy or laparotomy is necessary to manage biliary ascites not amenable to percutaneous drainage.

Operative management begins in the same fashion as with other abdominal injuries. A midline laparotomy is the most versatile approach for managing any liver injury that might be encountered. The falciform ligament is divided and perihepatic sponges are placed to manage bleeding from the liver temporarily. A fixed retractor is placed to expose the right upper quadrant structures. With perihepatic packing and manual compression, bleeding can be temporarily controlled and resuscitation provided. On patient stabilization, the packs are removed and the hepatic lacerations evaluated. Mild injuries with little or no ongoing bleeding may be managed with further compression, topical hemostatic agents, or suture hepatorrhaphy. Addressing these injuries may sometimes be facilitated by mobilizing the right or left hepatic lobes by dividing the triangular ligaments. This will allow injuries to be better exposed for interventions but may also allow better packing by optimizing anterior to posterior compression. Occasionally, however, when the risks of mobilization should be carefully considered if there is the possibility that the attachments of the liver are providing lifesaving tamponade of retrohepatic bleeding. This combination of superficial techniques will successfully manage most liver injuries encountered.

In the setting of more severe bleeding, a Pringle maneuver is a valuable adjunct. The hepatoduodenal ligament is encircled with a vessel loop or vascular clamp to occlude hepatic blood flow from the hepatic artery and portal vein. This maneuver helps distinguish hepatic venous bleeding, which persists from a portal vein, and hepatic artery bleeding that slows, allowing identification of sources of hemorrhage. The hepatic laceration can then be explored and any actively bleeding vessels controlled with suture ligation. Grossly devitalized hepatic parenchyma should be debrided when accessible and drains should be placed when injuries appear to be at risk for a bile leak. When feasible, a vascularized pedicle of omentum may be packed within the liver injury to reduce parenchymal bleeding and promote healing of the laceration.

Liver injuries in the vicinity of the retrohepatic vena cava that are not actively bleeding may benefit most from packing alone, without operative exploration. There are many heroic techniques seen in the literature that describe methods of repairing retrohepatic vena cava injuries, but it is likely that the approach with the greatest likelihood of success is maintaining the body’s natural tamponade of this low-pressure region when feasible. An atriocaval shunt (Shrock shunt) is one method that entails isolation of the retrohepatic vena cava by placing an intracaval shunt between the right atrium and infrahepatic vena cava. Isolation of the liver with an atriocaval shunt with the addition of a Pringle maneuver allows repair of the vena cava or hepatic veins without ongoing associated blood loss. Damage control techniques are often of great value because many patients who require operative intervention for liver injuries have already deteriorated physiologically. This approach includes control of surgical bleeding followed by aggressive perihepatic packing and temporary abdominal closure. It is fruitless to leave surgical bleeding and hope that packing alone will provide control. Similarly, it is futile to continue surgical attempts with sutures to control diffuse liver bleeding from coagulopathy. Patients are then resuscitated in the intensive care unit until hypothermia, coagulopathy, and acidosis resolve, at which time the abdomen is reexplored and the packs removed. Angiography with embolization after damage control may provide additional assistance with managing ongoing bleeding from hepatic artery branches, although the mortality in this patient cohort remains high.\(^n=43\)

**Gastric Injuries** Gastric injuries most commonly occur after penetrating abdominal trauma, with the stomach being the injured organ in approximately 17% of cases identified in two separate series from busy urban trauma centers.\(^n=33,461\) This is similar to contemporary data obtained from the NTDB in which 18.1% of penetrating abdominal trauma involved the stomach were associated with a mortality of 19.7%. Penetrating injuries are frequently full-thickness perforations resulting in the spillage of gastric contents. Conversely, blunt gastric injuries are rare, occurring in 0.05% of all blunt trauma patients and 4.3% of...
patients with a blunt hollow visceral injury. These injuries are associated with a significant mortality, reaching 28.2% in an EAST multi-institutional trial. In this series, gastric injury was independently associated with death when analyzed by regression analysis (relative risk [RR], 2.8; 95% confidence interval [CI], 1.8 to 4.4). Blunt gastric injuries are equally as rare in the NTDB and are associated with a mortality rate of 28.3%. The proposed mechanism of blunt gastric rupture is an acute increase in intraluminal pressure from external forces that results in bursting of the gastric wall. Because of the high-energy nature of this mechanism, associated injuries are common and often include the liver, spleen, pancreas, and small bowel. Mortality is frequently attributed to these associated injuries.

Gastric injuries will often be identified on physical examination by the presence of peritonitis. Some gastric injuries are identified by CT or DPL but the value of these modalities is limited. The evaluation of gastric injuries follows the approach to tach for other hollow abdominal viscera (see earlier).

Repair of gastric injuries is based on severity and injury location. Large intramural hematomas should be evacuated to ensure the absence of perforation, followed by control of bleeding and closure of the seromusculature with nonabsorbable suture. Full-thickness perforations should be debrided to remove nonviable gastric tissue and then closed with one or two layers. The perforation is generally closed with an absorbable suture, followed by inversion of the suture line with nonabsorbable seromuscular stitches. Because of the size and redundancy of the stomach, this can also be repaired with a stapling device. Perforations involving the gastroesophageal junction, lesser curve, fundus, and posterior wall may be more challenging to approach and require better exposure of the upper abdomen. Rarely, destructive injuries to the stomach involving large portions of the gastric wall require a partial or even total gastrectomy. Reconstruction options include a Billroth I or II gastroenterostomy or creation of a Roux-en-Y esophageojunostomy.

**Duodenal Injuries**

Duodenal injuries are uncommon after blunt and penetrating trauma but can be challenging to diagnose and manage. Most are caused by penetrating mechanisms occurring in 6.7% of penetrating abdominal cases, most of which the result of to gunshot wounds. The associated mortality is significant, 22.1% in the NTDB. Only 0.1% of patients experiencing blunt trauma sustain a duodenal injury. In those that present with a blunt hollow visceral injury, 12% are located in the duodenum. The mortality after blunt duodenal injury ranges from 11.4% to 14.8%. Blunt injuries are presumably caused by a blow to the epigastrium by a narrow object, resulting in contusion of the wall or a blowout secondary to acute elevation of intraluminal pressure. The classic description is the abdomen being struck by a steering wheel or, in children, a bicycle handlebar.

Although duodenal injuries after penetrating trauma are found at laparotomy, their identification after a blunt mechanism can be challenging and therefore require a high index of suspicion to avoid missed injuries. Because of the retroperitoneal location of a significant portion of the duodenum, physical examination findings may be limited. Even full-thickness perforations of the duodenum may not demonstrate peritoneal signs unless the perforation involves an intraperitoneal segment. The mainstay of evaluation for duodenal injury has become abdominal CT, with a low threshold for operative exploration. Findings on CT that reflect possible duodenal injury include thickened duodenal wall, air or fluid outside the bowel lumen, and contrast extravasation if oral contrast was administered. Some authors advocate the administration of oral contrast whereas others have found that it is not necessary with current imaging capabilities. Low-grade injuries resulting in a duodenal hematoma can be identified by CT, although it is important also to evaluate the pancreas because of a high rate of concomitant injury. Any indication of duodenal perforation on examination or imaging should prompt operative exploration. At times, the findings are subtle but a low threshold for exploration should be maintained because of the potential for false-negative interpretations of the CT scan. Upper GI contrast studies, DPL, and laboratory studies such as serum amylase level determination, have at most a limited role in the evaluation of duodenal injuries.

Management of duodenal injuries depends on the severity and location of the injury. Hematomas of the duodenal wall typically require no treatment unless they are large and result in a gastric outlet obstruction. Treatment of obstructing hematomas consists of gastric decompression and initiation of total parenteral nutrition, with reevaluation of gastric emptying with a contrast study after 5 to 7 days. If after 2 weeks of upper GI bowel rest the obstruction persists, exploration is warranted to evaluate for perforation, stricture, or associated pancreatic injury. Duodenal hematomas identified at the time of laparotomy for another indication require careful evaluation for perforation. Frequently, they decompress during duodenal mobilization, although intentionally opening the serosa to drain an incidentally identified hematoma should generally be avoided in the absence of a full-thickness injury.

Most full-thickness injuries of the duodenal wall can be repaired primarily using a single- or double-layer approach, depending on the amount of tissue available. Adequate mobilization of the duodenum with a wide Kocher maneuver is required to provide necessary exposure and ensure a tension-free repair. Duodenal transection can be managed with primary anastomosis as long as the ampulla is not involved and the segment is short. Larger segments of duodenal destruction may require more complex reconstruction, frequently using bypass around the injured duodenum. Any repair can be protected from the enteric contents by performing a pyloric exclusion and creating a gastroenterostomy. In the damage control setting, the use of a duodenostomy tube or resection leaving the GI tract in discontinuity is highly effective for controlling contamination temporarily.

**Pancreatic Injuries** Because of their adjacent location, injuries to the duodenum are frequently associated with pancreatic injuries. These are rare in blunt and penetrating mechanisms, occurring in only 0.09% of the patients in the NTDB. Of those that sustain penetrating injuries to the abdomen, the pancreas is involved in 6.6% of the cases. Despite the infrequency of these injuries, they remain a serious problem, resulting in mortality rates of 23.4% and 30.2% for blunt and penetrating mechanisms, respectively. These high mortality rates can frequently be attributed to delays in diagnosis and treatment. Because of the caustic nature of pancreatic enzymes, delays in managing pancreatic injuries result in massive systemic inflammation, with subsequent poor outcomes. Pancreatic injuries can result from direct penetration of the organ or through the transmission of blunt force energy to the retroperitoneum. A commonly identified mechanism involves the crushing of the body of the
pancreas between a rigid structure such as a steering wheel or seatbelt and the vertebral column. This can cause injury to the gland, ranging from mild contusion to complete transection with ductal disruption.

The diagnosis of pancreatic injuries can be extremely challenging and no single imaging modality has been found to be highly effective. As with the duodenum, the retroperitoneal location of the pancreas makes physical examination less helpful for diagnosis. Abdominal imaging with IV-enhanced CT can indicate the pancreatic injury but the sensitivity is limited for parenchymal injury and pancreatic duct disruption, as identified recently in a large multicenter trial.\(^4\) Depending on the generation of scanner used, the sensitivity for detecting parenchymal or ductal injury did not surpass 60%. Peitzman and colleagues\(^5\) have evaluated the usefulness of CT prospectively and found a somewhat better sensitivity, approximately 80%, likely reflecting the variations in radiologic interpretation among centers. Nevertheless, CT alone may not be satisfactory to rule out a pancreatic injury and a high index of suspicion must be maintained. Findings on CT that suggest pancreatic injury include malperfusion of the pancreatic parenchyma indicating disruption, surrounding fluid, or hematoma and stranding in the adjacent soft tissue. **Figure 18-25** demonstrates an injury at the neck of the pancreas on an abdominal CT scan.

Given the limitations of imaging pancreatic trauma, the detection of injuries may require the use of other modalities. Although these injuries are uncommon, there is great value in minimizing the time to diagnosis because any delays could be associated with worse outcomes. Patients who are not responding appropriately to their known injuries require further evaluation for missed injuries. In this setting, repeat CT scanning may suggest a pancreatic injury that required time to develop radiographically evident pancreatic inflammation. Although not predictive as a screening tool, elevated serum amylase levels may reflect pancreatic trauma when obtained more than 3 hours after admission. Serum amylase levels may be sensitive but little is known about their specificity; therefore, the use of this indicator is limited and should not be routinely used. Imaging of the pancreatic ducts with ERCP and magnetic resonance cholangiopancreatography (MRCP) may be helpful, especially for those patients who have a suggestion of pancreatic injury but a lack of supporting studies. These modalities continue to be evaluated, but they may occasionally be of assistance in planning therapy and determining an operative approach.

The mainstay of therapy for pancreatic injuries is surgical. Exposure of the entire gland to evaluate the pancreas comprehensively is required to exclude injury or select appropriate management. This exposure includes mobilization of the hepatic flexure of the colon and division of the gastrocolic ligament to retract the transverse colon and mesocolon inferiorly. A wide Kocher maneuver will mobilize the pancreatic head and facilitate evaluation. Assessment of the injury includes determining the degree of parenchymal involvement, location of the injury within the gland, and presence of pancreatic ductal involvement. The management of pancreatic injuries with ductal involvement depends on the location of the injury. Injuries to the left of the superior mesenteric vessels are managed with a distal pancreatectomy. The proximal stump can be managed by individually ligating the duct and overseeing the parenchyma or using a stapling device. Covering the stump with omentum may be advantageous and a closed suction drain should be placed. Managing injuries of the ductal system within the head of the pancreas can be more challenging. Although some advocate resection in this setting, the associated morbidity can be great, often necessitating a more conservative approach. Managing these injuries with drainage alone often successfully diverts the leakage of pancreatic fluid externally, creating a controlled fistula that frequently will close spontaneously. This healing may also be promoted with biliary decompression through the placement of stents via ERCP. Massive destruction of the pancreatic head with devitalized parenchyma or combined pancreatic and duodenal injuries may require a pancreaticoduodenectomy (Whipple procedure). This can be extremely challenging in this setting and is associated with a high postoperative complication rate. Performing a Whipple procedure in the setting of trauma requires ongoing patient stability or the operation should be abbreviated, with later reconstruction after the physiologic condition improves. Damage control for pancreatic injury includes hemorrhage control, external drainage, and temporary abdominal closure with plans for reexploration.

Adequate external drainage is an important principle in the management of most pancreatic injuries. The diversion of leaking pancreatic enzymes is required to prevent the devastating effects of uncontrolled accumulation of highly caustic digestive fluid, which will provoke a massive inflammatory response and progressive organ dysfunction. Pancreatic injuries not involving the pancreatic duct, including hematomas, parenchymal contusions, and lacerations of the capsule or superficial parenchyma, should be managed with external drainage alone. External drainage should be with a closed suction system because these are associated with a reduced rate of abscess development.\(^6\) Distal feeding access should be considered based on the overall clinical picture. **Figure 18-26** depicts an approach to the operative management of pancreatic injuries.

**Small Bowel Injuries** Depending on the series reviewed, the small intestine is one of the most frequently injured organs after penetrating abdominal trauma, likely secondary to the large percentage of the abdomen it occupies. Although the incidence of small

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**FIGURE 18-25** Pancreatic injury on abdominal CT scan. The injury involves the pancreatic neck and appears as a 2-cm segment of nonperfused pancreas tissue, with surrounding edema (arrow).
bowel injury after penetrating abdominal trauma has been described as high as 60%, these injuries are less common in the NTDB, identified in 21.8% of cases. Mortality rates range from 10% to 25%, with most caused by associated vascular injuries. Penetrating injuries can vary from tiny perforations to large destructive injuries that destroy circumferential segments of small bowel. Blunt, small intestinal injuries are less common, present in 2.7% of all blunt abdominal injuries in the NTDB, although these injuries are associated with a significant mortality rate of 16.3%. Mechanisms of blunt small bowel injury include crushing, rupture, and shearing types of patterns. The small bowel can be crushed between the steering wheel or seatbelt and a rigid structure such as the vertebral column, resulting in direct tissue injury. Similar forces can result in a rupture-type injury during which the intraluminal pressure rapidly increases, causing a blowout along the antimesenteric border. Finally, deceleration mechanisms can result in a shearing of the serosa or muscularis throughout a segment of small bowel. Mesenteric injuries can cause devascularization of sections of small bowel without direct tissue injury.

Small intestinal injuries are often identified at the time of laparotomy. Otherwise, the evaluation can be challenging and is similar to the approach to other hollow abdominal viscera. The use of imaging and other modalities has been described earlier.

The repair of small bowel injuries depends on the extent of intestinal wall destruction in relation to the luminal circumference. Serosal tears can be reinforced with interrupted nonabsorbable suture, which imbricates the injury. Small perforations that can be closed without compromising the intestinal lumen can be debrided and repaired with one or two layers. This can safely be performed for multiple perforations as long as closure will not result in obstruction of the enteric contents, although many choose resection when several injuries are close together. Injuries occupying over 50% of the intestinal wall circumference should be addressed with resection and anastomosis. There has been no difference demonstrated between stapled and hand-sewn anastomoses for intestinal resections. Selection of the anastomosis technique should be based on the experience of the surgeon, with the method of greatest comfort used. Hand-sewn anastomoses are frequently constructed in two layers but
single-layer methods are equally efficacious. The damage control approach to small bowel injuries includes rapid closure of perforations to control contamination and/or stapled resection of injured segments. Patients in shock may benefit from resection without immediate anastomosis because of related delays and a higher risk of anastomotic dehiscence. The abdomen is temporarily closed and the patient is resuscitated to correct physiologic derangements. Intestinal continuity can then be re-established on return to the operating room, following resuscitation.

Colon Injuries Similar to other hollow viscera, colon and rectal injuries occur most commonly after penetrating abdominal trauma and rarely after blunt mechanisms. The colon is one of the most frequently involved organs after penetrating abdominal trauma, occurring in 36% to 40% of patients in a series of 250 cases. This incidence is similar to data from the NTDB, in which 34.3% of all cases of penetrating abdominal trauma involved the colon or rectum. The associated mortality for colon and rectal injuries is the lowest of all the abdominal viscera. Penetrating injuries can range in the degree of colonic wall destruction, depending on the level of energy associated with the mechanism. Penetrating injuries can also be obscured by the retroperitoneal location of some segments of colon. Blunt colon and rectal injury occur in less than 1% of all blunt trauma patients but, in those patients with blunt hollow visceral injury, the colon or rectum is involved in 30.2% of cases. Mortality after blunt colon or rectal injury equals 16.3%, with much of this caused by associated injuries. Injuries to the colon can result from similar biomechanical mechanisms as those that occur in the small bowel. The colonic wall can be crushed by physical forces or rupture when the impact results in a rapid elevation in intraluminal pressure. Depending on the colonic segment involved, this perforation can occur into the retroperitoneum. The colon is also vulnerable to shearing forces, which can cause a separation of the serosa or muscularis over a long segment. Figure 18-27 demonstrates a segment of colon that was injured secondary to a shearing-type mechanism. Injury to the rectum can also occur when severe pelvic fractures result in a laceration by sharp bone fragments.

As with other hollow organ injuries, colonic injuries may be identified first at the time of laparotomy that was prompted by hemodynamic instability or the appropriate penetrating mechanism. Otherwise, evaluation is as described earlier for other hollow abdominal viscera. Care must be taken to assess segments of the colon that are retroperitoneal in location adequately.

Blood identified on rectal examination or a penetrating trajectory that suggests rectal involvement requires further evaluation. Rigid proctosigmoidoscopy can visualize the rectum and distal sigmoid colon to assist in determining the presence or absence of a rectal injury. This can be performed prior to laparotomy in hemodynamically stable patients to help plan the operative approach. Endoscopy may clearly reveal an injury to the rectum or only demonstrate hematoma in the rectal wall or a large amount of blood in the rectal vault. When possible, determining the size of the injury and location on the rectal wall may be valuable when planning the necessary management. Upper rectal injuries, especially those on the anterior or lateral surfaces, may be identified during examination of the pelvis during laparotomy.

Operative repair of colon injuries depends on the severity of the colonic wall injury and the patient’s overall condition. Historically, it was believed that all colon injuries required resection with the creation of a colostomy because of a high risk of anastomotic dehiscence. A substantial amount of work has been dedicated to determining whether proximal fecal diversion was necessary to manage colonic perforation. Several randomized prospective trials have concluded that primary repair or resection with primary anastomosis is safe in select patients, resulting in a leak rate that was not significantly greater than that for colonic diversion. Therefore, injuries that involve less than 50% of the colonic wall circumference can be repaired with one or two layers, being sure to imbricate the mucosal edge. Usually, compromising the colonic lumen is not as common a concern as in the small bowel. Destructive colon injuries that involve more than 50% of the colonic wall should be resected; many can then be anastomosed immediately. Injuries proximal to the middle colic artery are managed with a right hemicolectomy with creation of ileocolostomy, because this has been found to be a durable anastomosis. Distal injuries require segmental resection with colocolostomy anastomosis. In the setting of shock, immediate anastomosis may be associated with an unacceptably high leak rate and should be carefully considered.

There are two other options in the setting of hemodynamic instability to manage colon injuries. First, the injured segment can be resected and a diverting colostomy created. The second option is to resect the injured segment of colon and leave the GI tract in discontinuity until after the patient has been adequately resuscitated. On return visit to the operating room, delayed primary anastomosis or creation of a colostomy can be completed. Leak rates after delayed primary anastomosis have been found to be equivalent to immediate anastomosis performed in the setting of hemodynamic stability. Other concerns that may suggest colostomy instead of primary repair or anastomosis include significant associated injuries, underlying medical disease, and delayed injury recognition with the development of severe peritoneal inflammation.

Rectal injuries that result in perforation present a significant risk of developing pelvic sepsis and thus require operative management. The mainstays of treatment for rectal injuries are...
fecal diversion and presacral drainage until healing has occurred, at which time the colostomy is reversed. This can be achieved with an end colostomy or a loop configuration as long as complete fecal diversion can be achieved. Historically, drainage of the presacral space has been considered an important part of managing rectal perforations because of data generated in the military theater. More recently, some have countered this edict, concluding that presacral drainage is an unnecessary component, especially in the setting of low-energy, nonmilitary types of penetrating rectal trauma. Without definitive studies, one approach is to drain injuries that occur posteriorly or laterally, if in the lower third of the rectum, because these have likely entered the presacral space and are at greater risk of abscess formation. Other injuries to the extraperitoneal rectum can be managed with fecal diversion alone. Destructive rectal injuries that involve more than 50% of the rectal wall circumference may require resection of the rectum above the injury with the creation of an end colostomy.

**Abdominal Great Vessel Injuries** The great vessels of the abdomen are located within the retroperitoneum and abdominal mesenteries. Injuries to these vessels can be challenging to manage given the amount of blood loss that can be present when these structures are injured. Although these injuries frequently occur after blunt trauma, it is most commonly during penetrating injury that exploration of this region is required. Often, hematoma within the retroperitoneum is secondary to a pelvic fracture because hemorrhage from the pelvic vessels can dissect superiorly through the surrounding tissue. Abdominal vascular injuries are further addressed elsewhere in this text (Section 12, “Vascular Surgery”) so only those concepts related to initial assessment and management will be presented here.

Vascular injuries in the abdomen are often first recognized at the time of laparotomy for penetrating abdominal trauma. Frequently, these injuries are associated with significant ongoing blood loss and hemodynamic instability. Exploration of penetrating injuries to the retroperitoneum results in a definitive diagnosis. Penetrating injuries to the back frequently benefit from three-dimensional imaging, given that most do not enter the peritoneal cavity. Current CT can often identify the path of the injury and therefore suggest possible injury to adjacent structures. After blunt trauma, injuries to the abdominal vasculature with associated hematoma are often identified via contrast-enhanced CT. Occasionally, blunt trauma to the retroperitoneum with vascular injury is identified during urgently performed laparotomy, although further identification of specific injury depends on the location of the hematoma.

Usually, penetrating injuries to the retroperitoneum identified during laparotomy require exploration. Injuries to the abdominal vasculature are detailed in the vascular surgery section of this text, but a knowledge of the basic approach to and exposure of these structures is important. Hematomas in the vicinity of the right renal hilum or infrarenal vasculature benefit from a right medial visceral mobilization, also known as the Cattell-Brasch maneuver. A wide Kocher maneuver is performed and the peritoneal dissection is continued inferiorly to mobilize the right colon. The dissection is continue around the cecum and then superiorly up the mesenteric root, allowing all the abdominal viscera to be retracted to the left, thus exposing the midline vascular structures. Basic tenets of vascular repair are paramount, including proximal and distal control of the injured vessel, when feasible. Injuries to the left renal hilum or the suprarenal vessels can be exposed by performing a left medial visceral mobilization (the Mattox maneuver). This is performed by dividing the left lateral peritoneum from above the spleen to the distal left colon. The plane posterior to the colonic mesentery and e pancreas is developed and the abdominal viscera are retracted to the right to expose the superior retroperitoneal vasculature.

Blunt abdominal vascular injuries that are not actively bleeding may require operation to repair or, as more recently found, may be considered for endovascular therapy. When confronted with a retroperitoneal hematoma during laparotomy for blunt trauma, the location of the hematoma suggests the appropriate treatment. Figure 18-28 depicts three zones used to classify these hematomas. Zone 1 hematomas require exploration because these frequently involve the aorta, proximal visceral vessels, or inferior vena cava. An exception may be the dark hematoma behind the liver, which suggests a retrohepatic vena cava injury. These injuries may be best served by not exposing the contained low-pressure injury or by gently packing the surrounding area; heroic management techniques can be extremely challenging. A hematoma in the region of zone 2 should only be explored if it appears that the hematoma is expanding and continuing to lose blood. Finally, a hematoma in zone 3 is usually secondary to pelvic fracture bleeding and should not be explored unless exanguinating hemorrhage is present.

**FIGURE 18-28** Zones of the retroperitoneum visualized at the time of laparotomy. Zone 1 includes the central vascular structures, such as the aorta and vena cava. Zone 2 includes the kidneys and adjacent adrenal glands; zone 3 describes the retroperitoneum associated with the pelvic vasculature.
Genitourinary Injuries  The genitourinary organs include the kidneys, ureters, bladder, and urethra, all contained within the retroperitoneum. Injury to these structures results in bleeding or urine extravasation. Blunt mechanisms can result in renal laceration and bladder rupture, which can occur intraperitoneally or extraperitoneally. Commonly, bladder injuries are associated with pelvic fractures when significant energy is transmitted to the urine-filled bladder, resulting in wall rupture. All genitourinary structures are vulnerable to penetrating mechanisms, many of which cause urine extravasation.

The evaluation and management of genitourinary injuries are described elsewhere in this text (see Chapter 73) and therefore will be only briefly outlined. The presence of gross or microscopic hematuria is the most valuable screen for injuries to the genitourinary organs and should prompt further evaluation. Imaging with IV contrast-enhanced CT frequently identifies injuries to the genitourinary organs. Renal trauma, as well as injury to the adrenal glands, are easily identified on CT; imaging also allows an assessment for urine extravasation from the collecting system. Injury to the bladder can be evaluated by obtaining a cystogram, which is now most easily achieved with CT. In males specifically, blood at the urethral meatus and prostatic abnormality on rectal examination are suggestive of a urethral injury and require evaluation. This is best achieved by performing retrograde urethrogram, especially prior to placement of a urinary catheter. Penetrating genitourinary injuries may be identified at the time of laparotomy or suggested by imaging. Penetrating injuries to the back benefit from CT, which can characterize the injury tract and delineate adjacent organs.

During laparotomy for penetrating trauma, injuries to the kidney should be explored to ensure hemostasis but also to assess for a urine leak. Obtaining proximal control at the renal hilum is ideal and should be performed whenever possible. Many renal injuries are hemostatic at the time of exploration whereas others respond favorably to simple techniques. Devastating renal injuries, especially in the setting of shock with ongoing bleeding, may require nephrectomy after assessing the contralateral side for a kidney. Ureteral injuries require repair for which there are many described techniques, ranging from primary repair to nephrectomy. Intraperitoneal bladder injuries can be repaired in two layers of absorbable suture and the bladder drained with a Foley catheter or suprapubic cystostomy tube. Extraperitoneal bladder ruptures require only catheter drainage, with a follow-up cystogram to confirm healing.

Blunt retroperitoneal injury is most commonly identified on imaging and can be managed nonoperatively in most cases. Bleeding from the kidneys and adrenal glands is commonly self-limiting and requires no specific intervention. Nonoperative management requires clinical stability, which indicates the lack of ongoing blood loss. Deterioration mandates laparotomy, with management of uncontrolled bleeding. Patients with hemodynamic stability but pseudoaneurysm from a renal laceration on imaging may benefit from angioembolization. Renal hematomas after blunt trauma identified at laparotomy for other injuries should only be explored if it appears that the hematoma is expanding because this likely indicates ongoing hemorrhage.

Injuries to the Pelvis and Lower Extremities  Orthopedic injuries to the pelvis and extremities are extremely common and are covered in depth elsewhere in this text. An approach to management as it relates to the general or trauma surgeon is presented here. Orthopedic injuries constituted the greatest number of cases in the 2009 NTDB, with 27.5% of patients having upper extremity and 35.1% having lower extremity trauma. Fortunately, the mortality is low for each group, just below 4%, but the long-term morbidity can be high. Pelvic fractures alone were seen in 6.4% of cases and had a substantially greater mortality, approximately 9%. A variety of physical mechanisms are responsible for orthopedic injuries, with MVAs and falls being the most common causes.

Open fractures are frequently easy to identify on initial examination, as are those with severe deformity. Plain radiography remained highly effective for diagnosis but CT has attained a greater role, especially with complex fracture patterns. Pelvic fractures are typically identified on initial pelvic radiography and then better characterized if an abdominal or pelvic CT is obtained. Although CT demonstrates the bony injury accurately, it also can identify an associated hematoma and the presence or absence of active contrast extravasation, which appears as high-density material, frequently within the hematoma. Extremity examination must include a thorough vascular assessment and evaluation for compartment syndrome. Evidence of vascular insufficiency or bleeding may require angiography to localize and characterize the injury. The role of CT angiography of the extremities remains to be elucidated.

The diagnosis and management of hemorrhage from pelvic fractures represents a unique challenge that requires a standardized approach involving a number of disciplines. Figure 18-29 presents an approach to these injuries. Unstable patients should have a pelvic radiograph quickly obtained and interpreted for pelvic fracture. An important point is that although some pelvic fracture patterns are more likely to bleed, any fracture is capable of bleeding and should not be disregarded in the unstable patient. Pelvic fractures that demonstrate an increase in pelvic volume should be compressed with a pelvic binder or sheet wrapped around the hips to reduce the space available for hematoma formation. This will frequently manage venous bleeding. Ongoing instability suggests an arterial source, which should be addressed with angiography and embolization if these resources are available. Embolization may also be warranted in those patients, with active contrast extravasation identified by pelvic CT. Some recent work has suggested that packing of the pelvis may be an alternative to embolization, especially when endovascular therapy is not immediately available. Stabilization of the pelvic ring with external fixation is then performed to maintain reduction of the pelvic volume and reduce ongoing venous bleeding.

REHABILITATION  Although the acute management of injuries plays the greatest role in the reduction of mortality, it is the process of rehabilitation that functions to reduce the morbidity of injury. The rehabilitation process can be substantially longer than the hospital phase of care and is indispensible in restoring functionality and allowing patients to return to productive lives after severe injury. Much emphasis is placed on trauma-related fatalities, but there were approximately 30 million nonfatal injuries in 2008, many of which were severe and required some form of rehabilitation.

The rehabilitation process begins soon after the acute needs of the injured patient have been met. Hospital physical and occupational therapists frequently begin the process by initiating therapy and assessing which resources may be required when the
patient leaves the hospital. With these recommendations available, case managers and social workers can begin the process of identifying available resources in the inpatient or outpatient setting to address the unique rehabilitation needs of the patient. More robust systems have regular input from the rehabilitation team to assist in expediting referrals and transfer to appropriate facilities. Many patients benefit from generic rehabilitation services, but some patient groups have unique needs, such as rehabilitation centers that focus on the recovery from traumatic brain and spinal cord injuries. These two patient cohorts have specific needs that are best addressed at centers with specialized expertise. Hospitals committed to the care of the injured patient must be sure to place adequate priority on reinforcing the rehabilitation process, because this clearly is one of the most important aspects of a patient’s long-term recovery.

SELECTED REFERENCES
American College of Surgeons: Advanced trauma life support for doctors, ed 8, Chicago, 2008, American College of Surgeons.

First released over 25 years ago, this ATLS course revolutionized the initial approach to the injured patient. The eighth edition contains the same systematic approach that has been taught since the initiation of the course, as well as a greater emphasis on the underlying support from the literature. This edition is the first to be released as a textbook rather than as a course manual and contains significantly revised text, tables, and figures.


These guidelines represent the most comprehensive compilation of all literature related to traumatic brain injury. It is organized into evidence-based guidelines based on the strength of the associated studies. This document has been revised three times and therefore includes the most current published guidelines. Application of the guidelines has been associated with improved outcomes after traumatic brain injury.

Committee on Trauma, American College of Surgeons: Resources for the optimal care of the injured patient, ed 5, Chicago, 2006, American College of Surgeons.

This document outlines the necessary components for the optimal management of injured patients in a trauma center. Known as the Green
Book, this resource was developed by the Committee on Trauma and is frequently updated to remain current. The requirements to become verified as a trauma center and then maintain verification are contained within this document.


This textbook is the comprehensive resource for all injury specific information. Chapters incorporate all recent literature and provides an excellent presentation of all injuries sustained by the trauma patient. The text is frequently revised and chapters are written by world leaders in each specific subject matter.


The National Study on Costs and Outcomes of Trauma (NSCOT), a large multicenter project supported by the Centers for Disease Control and Prevention, was initiated to define variations in injury care and outcomes between trauma and nontrauma centers. The project included over 5000 patients from 69 hospitals, spanning 12 states. This study demonstrated the benefit of care provided at a trauma center versus a nontrauma center. After correction for injury severity, trauma center care was associated with a reduction in in-hospital mortality (7.6% versus 9.5%; relative risk, 0.80; 95% confidence interval, 0.66 to 0.98), as well as 1-year mortality (10.4% versus 13.8%; relative risk, 0.75; 95% confidence interval, 0.60 to 0.95).


This study demonstrated the benefit of establishing a systematic method of managing trauma from the time of injury through the rehabilitation process. During a 17-year period, over 400,000 vehicle-related fatalities throughout the United States were evaluated to help establish a trauma system. The study identified a mortality benefit of 8% from trauma system development.


This landmark publication revealed the substandard way in which injury and other emergency medical care was being provided in the United States. This document prompted the development of and improvement in emergency medical systems. Considered to be the white paper of emergency care, it provides valuable perspective regarding the maturation of modern emergency medical services.


This article was the first to present the concept of damage control, which has become the standard of care in managing multiple severe injuries. It was not until the development of this approach did surgeons use the abbreviation of abdominal surgery to prevent the deadly cycle of worsening hypothermia, coagulopathy, and acidosis. Based on the success of this methodology, other areas of trauma management, such as orthopedics and resuscitation, have developed similar approaches.


In response to studies that demonstrated a paucity of trauma systems in the United States, the Health Resources and Services Administration released this document which outlines how systems for the management of injuries are developed and evaluated. It emphasizes the value of a public health approach to trauma care. It has also been valuable in securing governmental funding for trauma system development.

REFERENCES

1. Committee on Trauma, American College of Surgeons: Resources for the optimal care of the injured patient, ed 5, Chicago, 2006, American College of Surgeons.


