Chapter 11
Advanced Trauma Life Support

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Initial Assessment

Implementing a systematic approach to the initial assessment of a trauma patient is critical. By following a methodical system, the trauma team may rapidly identify and address immediate life-threatening injuries. If done well, it can also serve to provide a degree of organization to a frequently chaotic environment. A successful initial assessment starts before the patient arrives. The team leaders must identify themselves and begin the room setup and team task allocation. This includes identifying personnel available to assist, establishing roles and expectations for each role, and ensuring the availability of appropriate equipment for procedures. Involved personnel often include clinicians to help secure the airway; respiratory therapy personnel; X-ray technologists; and nurses to establish rapid intravenous (IV) access, obtain vital signs, administer medications, and document critical events. Additional staff may be useful to assist with cardiopulmonary resuscitation (CPR) or other procedures, if indicated. It is also important to ensure the room is quiet and that closed loop communication is employed. Procedural supplies should include difficult airway kits, chest tubes with appropriate drainage systems, large bore central venous access kits, intra-arterial blood pressure monitoring systems, rapid IV infusers, and blood product availability.

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A, B, C, D, E

The most widely used trauma initial assessment includes a primary and secondary survey. The primary survey is encapsulated by the mnemonic “ABCDE” (Airway, Breathing, Circulation, Disability, Exposure); however, massive exsanguination should be controlled immediately when identified. Particularly for those who do not routinely perform trauma assessments, it is important to address each step sequentially rather than in parallel to ensure nothing is missed. An axiom during the primary survey is “resuscitate first.” For instance, in a severely hypotensive patient who requires definitive airway management, blood transfusions should occur before and during airway management. The primary survey can and should be repeated whenever deemed necessary, given any clinical change or deterioration. Once the primary survey is complete, the team can perform a secondary survey which includes a thorough history and head-to-toe physical examination, complemented by appropriate imaging modalities.

Primary Survey

It is important to note that while basic life support (BLS), advanced cardiovascular life support (ACLS), and some military trauma programs now prioritize circulation and massive exsanguination over airway and breathing, current algorithms for advanced trauma life support (ATLS®) still maintain the traditional “ABCDE” pathway [1].

Airway management is addressed in a subsequent section of this chapter. Once the airway has been secured, evaluation of breathing demands assessment of the patient’s ability to ventilate. Assessment includes the visual inspection of breathing, respiratory rate and effort, and auscultation of bilateral breath sounds. If hemodynamically unstable patients are found to have diminished or absent breath sounds in the appropriate setting, this should prompt concern for tension pneumothorax and may indicate the need for rapid decompression. Chest decompression should involve placement of a needle, finger, or tube thoracostomy in the fourth or fifth intercostal space in the anterior axillary line. Several studies have demonstrated higher success of needle decompression with the anterior axillary position compared to the previously accepted second intercostal space in the midclavicular line [2–4].

Shock Prevention

The priority is establishing the patient’s vital signs and rapidly identifying potential shock states. If found to be in shock, hemorrhagic shock should be considered and resuscitation with blood products should commence as soon as possible. Up to 1 L of crystalloid in 500 mL increments is still an acceptable starting point, particularly if non-hemorrhagic causes of shock are still being considered; however, these fluids have often already been administered in the field. If a patient remains hypotensive after initial crystalloid resuscitation, blood product transfusion should be considered. If available, whole blood may be superior to traditional low-ratio 1:1:1 (1 unit of packed red blood cells [PRBCs] to 1 unit of fresh frozen plasma [FFP] to 1 unit of platelets) resuscitation and should also be considered for patients in hemorrhagic shock.

Large bore IV access should be rapidly obtained. If unable to obtain peripheral IV access efficiently, central access should not be delayed. Any external hemorrhage must also be identified and controlled. Peripheral pulses should be evaluated in each extremity and discrepancies between the extremities noted and appropriately evaluated during the secondary survey.

Glasgow Score

Disability refers to prompt evaluation of the patient's neurologic status, to identify time-sensitive traumatic brain or spinal cord injuries. A Glasgow Coma Scale (GCS) score should be obtained on presentation. If possible, it is preferred to obtain a full GCS prior to administration of paralytics and sedation to identify a baseline and any need for urgent osmotic therapy or time sensitive imaging.

Exposure involves removal of the patient's clothing and a full body inspection. This is particularly important in penetrating trauma patients who may have hidden wounds in their skin folds, axilla, or perineum that could drastically alter subsequent management. The patient should be rolled and their back as well as cervical spine examined for posterior injuries.

Imaging Procedures

In critically ill or hemodynamically unstable patients, it may be important to obtain adjunct testing immediately after completion of the primary survey, to help identify the potential source of their current clinical status. These tests are often essential to help guide surgical planning and exploration (i.e., which body cavity to enter), particularly in the setting of blunt trauma with an unknown source of hemorrhage. These adjuncts include chest X-ray; Focused Assessment with Sonography for Trauma (FAST) examination or Extended-FAST (e-FAST), which includes a pleural assessment; and pelvic X-ray. In addition to allowing rapid identification of life-threatening pneumothorax or hemothorax and position of invasive lines or tubes, chest X-rays also provide insight into the mediastinum and aortic knob and sometimes may indicate aortic injury and associated mediastinal hematoma.

The FAST exam can be done quickly at the bedside to assess the dependent portions of the abdomen for free fluid as well as examine the pericardium in the subxiphoid location to evaluate for tamponade. However, sensitivity and specificity of this examination remains operator dependent. E-FAST adds the evaluation of lung sliding on the anterior chest, which if done properly may be more sensitive for smaller pneumothoraces than chest X-ray. Chest radiographs and FAST examinations can and should be repeated if a relevant change in clinical status is noted.

Pelvic radiographs can be done quickly to identify unstable pelvic fractures which are often accompanied by vascular injuries. Identification of an unstable pelvic fracture should prompt application of a pelvic binder and early discussion with specialists from interventional radiology, vascular surgery, and orthopedic surgery, depending on the patient's clinical status.

Secondary Inspection

A secondary survey, including a full history and head-to-toe physical examination should be completed after the primary survey is conducted. Neurologic and vascular examinations of each extremity should be performed and documented. Medications, particularly anticoagulants and cardiac medications, should be noted as these agents may have significant impacts on the patient's trauma physiology and the trauma team's approach to interventions.

Once the primary and secondary surveys and adjunct testing are complete, further laboratory and radiographic testing should be undertaken based on the patient's clinical status and signs and symptoms, as appropriate.

Airway and Ventilation Management

Many severely injured patients will require definitive airway management. A definitive airway is defined as a cuffed tube, placed in the trachea, which enables the provision of positive pressure ventilation. Endotracheal intubation is the most employed technique; only about 0.3% of trauma patients will require a surgical airway, either in the form of cricothyrotomy or tracheostomy [5]. Intubation may be required in situations of trauma-associated cardiac arrest, agitation, inability to protect the airway (e.g., blood pooling, emesis, altered mental status, GCS $\leq$8), or impending risk of airway obstruction (e.g., neck hematoma, inflammatory changes associated with noxious chemical inhalation).

Intubation may also be used when high opioid use is required for pain control. The technique with the highest likelihood of success based on clinical acumen should be employed. Multiple studies have compared video laryngoscopy to direct laryngoscopy with varying results. Video laryngoscopy is likely superior to direct laryngoscopy for patients with predicted difficult airways and has a higher first pass success rate [6].

Aspiration of Gastric Contents

Injured patients who present to the hospital should be presumed to have a full stomach and identified as high risk for pulmonary aspiration. Therefore, rapid sequence induction and intubation (RSII) should be performed. The key principles behind RSII are avoidance of mask ventilation, and pre-oxygenation should be performed via passive methods (e.g., nasal cannula, non-rebreather mask). Patients with spontaneous respiratory effort who do not achieve adequate ventilation due to soft tissue obstruction in the oropharynx may benefit from placement of a nasopharyngeal or oropharyngeal airway. Mixed data supports the avoidance of nasopharyngeal tubes in patients believed to have unstable midface and base of skull fractures.

The “Sellick maneuver” (i.e., cricoid pressure) is no longer recommended in traumatic airway management due to its potential to worsen optimal intubation views, and because of the lack of training for potential assistants to apply effective cricoid pressure. The clinician responsible for airway management should be prepared to complete laryngoscopy with a cervical collar in place. Yet, with well-trained personnel and clear communication, manual in-line stabilization with removal of the anterior segment of the cervical collar will be of benefit to hasten laryngoscopic placement and assist in optimal mouth opening. Care should be taken to avoid neck hyperextension and maintenance of a sniffing position.

Anesthetics and Vasoactive Interactions

Patient hemodynamics and mechanism of injury will assist in determining which induction agents will be appropriate. In patients with profound hypotension, propofol is typically avoided due to its systemic vasodilatory properties. More hemodynamically neutral induction agents such as etomidate and ketamine are better tolerated in hypotensive patients. Small doses of benzodiazepines (e.g., midazolam) or opioids (e.g., fentanyl) may be used as adjuncts to decrease the dose of other sedative-hypnotics required for unconsciousness.

For paralysis, succinylcholine may be used if rapid reversibility is desired, but its administration should be avoided in patients with identified motor neuron disease, prior history of paralysis, muscular dystrophies, crush injury, and high injury severity scale poly-trauma, and severe burns more than 24 h after onset.

In children receiving succinylcholine, an anticholinergic agent such as atropine or glycopyrrolate should be co-administered due to risk for succinylcholine-induced bradycardia. Rocuronium, a non-depolarizing neuromuscular blocking agent, may be used at a higher dose (1.2 mg/kg) for RSII to achieve quicker onset and similar intubating conditions to succinylcholine [7]. Patients arriving to the trauma resuscitation bay in cardiac arrest may be intubated without medications, and sedation later initiated if return of spontaneous circulation is achieved.

Intubation and Ventilation

Endotracheal tubes (ETTs) are sized according to their internal diameter in millimeters. An 8.0 mm ETT is usually appropriate for most adult males, and a 7.0 mm is usually appropriate for most adult females. New recommendations include the use of cuffed ETTs for pediatric patients according to the following formula: Cuffed ETT Size = (Age ÷ 4) + 3.5. Uncuffed ETTs should be used only in infants. If intubation and mask ventilation both prove impossible, a supraglottic airway should be inserted, according to the American Society of Anesthesiologists difficult airway algorithm [8]. Care should be taken to limit peak airway pressures when a supraglottic airway is in place, to avoid insufflating the stomach. If insertion of a supraglottic airway proves unsuccessful, then placement of a surgical airway should be undertaken.

Moderate Ventilation Peaks

Lung-protective ventilation with tidal volumes of 6–8 mL/kg of ideal body weight should be employed after a secure airway is established. Peak and plateau pressures should be monitored closely due to the potential for positive pressure ventilation to worsen hemodynamic instability and any pre-existing airway or pulmonary pathology. If hemodynamic collapse occurs after initiation of positive pressure ventilation, hypovolemia and tension pneumothorax should be assumed and bilateral needle/finger/tube thoracostomies performed expeditiously, while infusing IV fluids or blood products. As discussed later in this chapter, a lower $PaCO_2$ of 30–35 mmHg should be targeted for patients with suspected impending intracerebral herniation from an associated traumatic brain injury.

Shock

Shock is defined as a state of relative end organ hypoperfusion and may progress to multisystem organ failure if allowed to proceed unchecked. Resuscitation in trauma should be aimed at maintaining and reassessing adequate oxygen delivery. If intravenous access is not immediately obtained in the unstable trauma patient, intraosseous access should be obtained. The proximal or distal tibia and the proximal humerus are the preferred sites, and commercially available devices/kits should be employed for safety and efficacy. Most patients following trauma will benefit as well from the placement of arterial catheters for closer hemodynamic monitoring, as much as for large bore central venous catheters.

Though the most common etiology of shock in trauma is hemorrhagic shock, other etiologies such as cardiogenic, obstructive, distributive, and neurogenic should be considered. The FAST examination is employed to rapidly exclude common life-threatening injuries such as pericardial tamponade, abdominal organ injury, and with the e-FAST, pneumothorax.

Fluid Replenishment

Hemorrhage is classified by the American College of Surgeons into a four-tiered system (Table 11.1) [1]. Recent updates to ATLS® include the addition of pulse pressure and base excess, as both have been shown to correlate with the degree of hypovolemia due to hemorrhage [9, 10]. Limited crystalloid may be appropriate for resuscitation from Class I or Class II hemorrhage; When blood products are available, blood should be the mainstay of volume resuscitation until hemorrhage has been controlled. When hemorrhage is ongoing, damage control resuscitation is undertaken, allowing permissive hypotension with systolic blood pressure (SBP) ≥90 mmHg and a mean arterial pressure (MAP) of 50–65 mmHg. Once hemorrhage is controlled, a MAP of ≥65 is ideal for sufficient end organ perfusion.

Patients with hemorrhagic shock following trauma should receive blood products and possibly tranexamic acid (TXA; ideally with the first dose administered within 1 h of injury). Crystalloid administration should be limited because it causes hemodilution and decreases clot formation and strength. In emergent situations where blood typing has not yet occurred, type O blood should be given. Rh-negative

Table 11.1 Classification of hemorrhage

	Class I	Class II	Class III	Class IV
Blood loss (% of blood volume)	<15%	15–30%	31–40%	>40%
Heart rate	↔	↔/↑	↑	↑/↑↑
Blood pressure	↔	↔	↔/↓	↓
Pulse pressure	↔	↓	↓	↓
Respiratory rate	↔	↔	↔/↑	↑
Urine output	↔	↔	↓	↓↓
Glasgow Coma Scale	↔	↔	↓	↓
Base excess	0 to −2 mEq/L	−2 to −6 mEq/L	−6 to −10 mEq/L	−10 mEq/L or less
Resuscitation required?	No	Crystalloid or blood	Blood	Massive transfusion
Responsive to fluid bolus?	Responsive	Transiently responsive, then worsening	Transiently responsive, then worsening	Non-responsive
Need for surgical intervention?	Possibly	Likely	More likely	Most likely

Adapted from American College of Surgeons Committee on Trauma. Advanced Trauma Life Support (ATLS®) Student Course Manual, 10th, 2018 [1] blood should be given to women of childbearing age to avoid alloimmunization that may complicate future pregnancies; for those pregnant, Rho(D) immune globulin should be administered.

A widely adopted protocol for blood and blood products recommends a ratio of 1 unit of PRBCs to 1 unit of FFP to 1 unit of platelets. Whole blood may be superior to this component therapy, but actual benefit has yet to be determined in larger randomized controlled trials. Ionized calcium levels decrease with massive transfusion and should be monitored closely and repleted empirically (i.e., 1 g calcium chloride for every 4–6 units of blood transfused).

Tissue Perfusion and Coagulation

Adequacy of resuscitation may be assessed in many ways, including the monitoring of serial blood lactate levels, base excess, urine output, mental status, and central venous oxygen saturation. Patients who have sustained traumatic injuries frequently present to the hospital with coagulopathy. Hypothermia and acidosis present on admission can negatively impact coagulopathy and mortality, so resuscitation fluids should be warmed before administration. Point of care coagulation testing, namely thromboelastography [TEG] or rotational thromboelastometry [ROTEM] can provide valuable information about the patient's coagulation status. Administration of TXA was shown to improve all-cause mortality in the CRASH-2 trial [11], but its use continues to be debated.

Neurogenic Circulatory Shock

Neurogenic shock should be suspected in patients with spinal cord injuries with concomitant bradycardia and hypotension. In patients with neurogenic shock without hemorrhagic shock, norepinephrine, epinephrine, selective alpha-1 agonists, and volume resuscitation with crystalloid should be used to maintain adequate perfusion of the spinal cord and end organs to avoid secondary insults.

Thoracic Trauma

Thoracic injuries occur in 10–30% of all trauma patients [12, 13]. Most injuries to the chest can be managed non-operatively with less than 10% of blunt chest injuries and between 15–30% of penetrating chest injuries requiring an operation [1]. Occult pneumothoraces and hemothoraces (i.e., seen on CT scan but not on chest X-ray) in an otherwise stable patient may even be observed with repeat imaging—without tube thoracostomy—pending the patient's clinical course. If tube thoracostomy is indicated for pneumothorax or hemothorax, minor bleeding and most air leaks will cease on their own with pleural apposition, if a well-positioned chest tube is placed.

Rib Fractures

They are associated with a poor prognosis and increased mortality in the elderly population, and pain is treated aggressively to avoid respiratory splinting which may lead to atelectasis and pneumonia. In severe cases, epidural analgesia may be offered. Studies have demonstrated a mortality and pneumonia risk of approximately 20–30% in those older than 65, with a 19% increase in mortality per additional rib fracture [14]. Although most thoracic trauma is non-operative, prompt recognition of critical thoracic injuries is essential. Immediate life-threatening chest injuries requiring urgent intervention include tension pneumothorax/hemothorax, massive hemothorax, cardiac tamponade, and thoracic aortic injury.

Tension Pneumothorax

Tension pneumothorax should be diagnosed based on physiology, history, and physical exam alone. A trauma patient with decreased breath sounds, tachycardia, and hypotension should be considered to have a tension pneumothorax with impending cardiovascular collapse and a decompressive procedure (i.e., needle, finger, or tube thoracostomy) should be performed to prevent cardiac arrest.

Physiologically this occurs in the setting of a "one way valve" leading to ongoing air accumulation in the pleural space and increased intrathoracic pressure. Ultimately, this increase in pressure begins to compromise venous return with subsequent cardiovascular collapse. Physical exam findings include tracheal deviation away from the side of injury; jugular venous distention; and hyper-resonance to percussion on the affected side. Jugular venous distention may not be appreciated in massive hemothorax if the patient is intravascularly depleted.

Tension pneumothorax may be addressed either by tube thoracostomy or in pre-hospital situations, needle decompression. ATLS® has now adopted the anterior axillary approach in the fifth intercostal space as the preferred location for needle decompression of a pneumothorax [1–4].

Major Hemothorax

Massive hemothorax is defined as a hemothorax with more than 1500 mL blood evacuated with initial chest tube placement or more than 200 mL/h. over 4 h. This degree of ongoing bleeding suggests that the source of hemorrhage is significant and unlikely to resolve with simple chest tube placement and pleural apposition. Surgical exploration is indicated to identify the underlying source of bleeding and stop the hemorrhage. On physical examination, massive hemothorax is associated with dullness to percussion and collapsed neck veins due to intravascular volume depletion from massive hemorrhage. For the treatment of any hemothorax, ATLS® previously recommended placement of a large bore tube thoracostomy. Recent studies have demonstrated that the diameter (size) of the tube does not affect the ability to evacuate a fresh traumatic hemothorax. Therefore, ATLS® now recommends placement of a smaller 28–32 Fr chest tube for any acute hemothorax that is visible on chest radiograph [15].

Aortic Damage

Blunt thoracic aortic injury may be life threatening. If no contraindication exists, ATLS® now recommends impulse control with a short-acting beta-1 blocker (i.e., esmolol) to decrease the heart rate to <80 beats per minute and a target mean arterial pressure of 60–70 mmHg with the goal of reducing wall stress and thus the risk for rupture or worsening of an existing injury. Early computed tomography angiography (CTA) should be considered as well as consultation with a vascular or cardiothoracic surgeon. Endovascular repair of aortic injuries has largely replaced open repair as the preferred technique. Large commercial stents suitable for the proximal aorta can now be introduced and positioned through the femoral artery. In exceptional conditions when the damage encompasses the origin of large branches (carotid, subclavian artery), customized stents can be ordered, although these are extremely costly and take some time to be manufactured.

Cardiac Damage and Pericardial Tamponade

Significant cardiac injury is relatively uncommon in both blunt and penetrating trauma but can be highly lethal due to gradual accumulation of blood in the pericardial sac causing tamponade. Hypotensive patients with chest trauma should have prompt investigation of the pericardium with cardiac ultrasonography. This is most often performed during the initial FAST exam or later by a formal echocardiogram. A concomitant left-sided hemothorax may obscure the traditional ultrasound windows, contributing to false positive or false negative results. If tamponade is identified, the patient will likely require a sternotomy for exploration of the heart and definitive repair. Sternal fractures may also be noted in patients with blunt cardiac injury.

The most common presenting rhythm in blunt cardiac injury is sinus tachycardia, although other arrhythmias such as atrial fibrillation are possible. Elevations in cardiac troponin are common with blunt cardiac injury, and levels should be trended. The Eastern Association for the Surgery of Trauma (EAST) guidelines allow the trauma team to rule out a blunt cardiac injury in those with a normal electrocardiogram (ECG) and negative troponins, thus obviating the need for further cardiac monitoring. Continuous telemetry monitoring should be undertaken in those with new onset arrhythmias. The role of echocardiography is in those with a persistent new arrhythmia or in those with hypotension without an evident source of hemorrhage.

Penetrating Abdominal Trauma (Gunshot or Stab Wound), Unstable

Patients with penetrating truncal trauma who are hemodynamically unstable, have peritonitis on physical examination, or have evisceration warrant surgical exploration in the form of a laparotomy after primary survey. Adjuncts in the form of a chest X-ray and foreign body X-ray series in gunshot victims may serve to provide additional clues regarding trajectory and retained projectiles, however should not delay operative intervention.

Penetrating Abdominal Trauma, Gunshot, Stable

Patients who present after gunshot to the abdomen almost universally require abdominal exploration if peritoneal violation is suspected. Many institutions advocate for proceeding to the operating room emergently for exploratory laparotomy after primary survey, chest X-ray, and foreign body series X-rays. A FAST examination may be helpful, though it is not mandatory as a negative FAST does not rule out peritoneal violation, hollow viscus injury, and retroperitoneal organ pathology. Computed tomography (CT) scan often does not change management and simply prolongs time to surgical incision, although some high-volume centers routinely perform pre-operative CT scan to help guide operative planning with trajectory assessment, if it can be done efficiently.

If there is suspicion of a tangential gunshot wound (i.e., does not enter the peritoneum), a CT scan may be helpful and can often indicate in favor of non-operative management. There are some high-volume trauma centers that manage isolated, stable right upper quadrant hepatic gunshot wounds with CT imaging and observation, with or without angioembolization, though this approach is still debated [16].

Penetrating Abdominal Trauma, Stab Wound, Stable

If there is evidence of peritonitis or evisceration on arrival, the patient should proceed for operative intervention. If there is no peritonitis or evident evisceration, EAST guidelines recommend obtaining CT imaging with contrast to help stratify patients [16]. CT imaging with IV contrast, encompassing rectal contrast for penetrating flank wounds, remains widely utilized however continues to be a topic of debate. Diagnostic laparoscopy has been proposed as a method of screening to determine peritoneal violation in these patients. If positive for peritoneal violation, the procedure in most cases is converted to a laparotomy for formal exploration. Diagnostic laparoscopy has also been used for thoracoabdominal stab wounds in the evaluation of diaphragmatic injuries.

As advancements in minimally invasive surgery continue, some institutions are performing laparoscopic exploration and repair of simple injuries, though this remains highly dependent on surgeon experience and skill. If non-operative management is pursued for an equivocal diagnosis, serial abdominal exams are performed for 24 h unless there is clear evidence that the peritoneum was not violated. Less commonly used methods include diagnostic peritoneal lavage and local wound exploration to determine peritoneal violation. Both have been found to result in higher rates of non-therapeutic laparotomy.

Penetrating Flank/Back Trauma, Stab Wound, Stable

Without violation of the peritoneum, patients may not develop peritonitis until late in their clinical course. They should undergo augmented CT imaging with double or triple contrast (oral, rectal, IV, or both IV and enteral) to evaluate retroperitoneal structures for violation; the specific protocol is institution dependent. Oral contrast should opacify the entire duodenum and rectal contrast should reach the ileocecal valve for the study to be adequate.

Penetrating Pelvic Trauma

Penetrating pelvic trauma can result in highly devastating injuries which are difficult to diagnose and treat. Major vascular injuries are possible as are bladder, ureteral, and rectal injuries. Trans-pelvic injuries may also enter the abdomen and cause intraperitoneal damage. Ideally, a CT scan with rectal and IV contrast should be obtained, although variability in rectal tube placement may result in false negative studies due to incomplete visualization of the distal rectum. If higher concern for rectal injury exists, direct visualization with proctoscopy can be performed. Delayed phase images and CT cystography may help identify genitourinary and bladder injuries.

Blunt Abdominal Trauma, Unstable

In general, blunt abdominal trauma patients with hemodynamic instability or peritonitis should proceed to the operating room for formal exploration without CT imaging after initial evaluation. These patients frequently present with significant abdominal tenderness, guarding, and rigidity, although concomitant traumatic brain or spinal cord injuries may cloud a thorough abdominal examination.

Blunt Abdominal Trauma, Stable

Most blunt trauma patients will have sustained some trauma to the chest, abdomen, or pelvis. If hemodynamically stable, these patients will typically undergo a CT scan with IV contrast. CT is a useful tool for evaluating solid organ, vascular, and genitourinary injuries, but it can miss hollow viscus injuries. A small amount of free fluid in the abdomen or thickening of a loop of bowel or mesentery should prompt concern for a bowel injury, thus indicating the need for observation, repeat imaging, or exploration.

Blunt Pelvic Trauma

Blunt trauma resulting in significant pelvic fractures can result in life-threatening hemorrhage. This can be due either to direct injury of major vasculature or to disruption of the sacral venous plexus. Patients may present with an open book or unstable pelvic fracture on physical examination, which should prompt quick application of a pelvic binder and closed reduction of the pelvis to help reduce this potential space. Expeditious consultation with an orthopedic surgeon should occur, and if ongoing bleeding is suspected, resuscitation with blood products should continue. Options for intervention include surgical preperitoneal packing, angioembolization, or placement of a zone three resuscitative endovascular balloon occlusion of the aorta (REBOA) device [17].

Head Trauma

Any patient with altered mental status following trauma should be considered to have acute neurologic injury. GCS is the most used method of evaluating the severity of any head injury (Table 11.2). Eye opening, verbal response, and motor response are evaluated as part of the GCS with a minimum of 1 and a maximum of 4, 5, and 6 points awarded in each category, respectively. When part of the evaluation is unable to be completed (e.g., when a patient is intubated), that category is designated as “non-testable” or “NT.” Severe head trauma is suspected when the presenting GCS is ≤8. Comorbid cervical spine injuries may also be seen in this patient population, as discussed elsewhere in this chapter.

Management of patients with traumatic brain injury is focused on maintaining cerebral perfusion pressure (CPP) and avoiding increased intracranial pressure

Table 11.2 Glasgow Coma Scale

Parameter	Score
Eye opening	
Spontaneous	4
To sound	3
To pressure	2
None	1
Non-testable	NT
Verbal response	
Oriented	5
Confused	4
Words	3
Sounds	2
None	1
Non-testable	NT
Motor response	
Obeys commands	6
Localizes	5
Normal flexion	4
Abnormal flexion	3
Extension	2
None	1
Non-testable	NT

Adapted from American College of Surgeons Committee on Trauma. Advanced Trauma Life Support (ATLS®) Student Course Manual, 10th, 2018 [1]

(ICP). The equation for cerebral perfusion pressure is as follows: **CPP = MAP − ICP**. The Brain Trauma Foundation recommends targeting a CPP of between 60–70 mmHg and ICP ≤22 mmHg. These targets are derived from a number of international trauma centers that require invasive intracerebral monitoring. Duration of systemic hypotension is inversely correlated with outcomes, likely due to secondary brain injury and ischemia [18]. Hyperventilation is a rescue maneuver that can be employed temporarily to decrease ICP by targeting a $PaCO_2$ of 30–35 mmHg. Administration of prophylactic anti-epileptics is recommended to prevent post-traumatic seizures in the instance of an intraparenchymal, subdural, or epidural hemorrhage.

Spine and Spinal Cord Trauma

Up to 8% of patients with a head injury will also have a cervical spine injury [19]. ATLS® guidelines have recently de-emphasized the use of "spinal immobilization" and instead favor "restriction of spinal motion." Backboard use should be limited and backboards removed promptly after arrival of the patient to the trauma bay, due to the potential for pressure injuries from the hard surface. The Canadian C-Spine Rule [20] and National Emergency X-Radiography Utilization Study (NEXUS)

Table 11.3 Summary of Canadian and NEXUS cervical spine rules for ruling out injury to the cervical spine [20, 21]

Canadian	NEXUS
Radiography **NOT** necessary if: Simple rear-end motor vehicle crash Sitting position in emergency department Ambulatory (at any time since injury) Delayed onset of neck pain No midline cervical spine tenderness Can rotate neck actively 45° to the right and left	Radiography **NOT** necessary if: No posterior midline cervical spine tenderness No evidence of intoxication Normal level of alertness No focal neurologic deficits No painful distracting injuries
Radiography **NECESSARY** before removal of cervical collar: Age >65 years Paresthesias in extremities Dangerous mechanism (fall from >3 feet [1 m] or 5 stairs, axial load to head, motor vehicle crash with high speed/ejection/rollover, motorized recreational vehicle or bike collision)	

criteria [21] have utility in excluding patients at low risk for cervical spine injury who may benefit from early removal of a cervical collar (Table 11.3).

Primary Neurogenic Shock

Patients with spinal cord injury may manifest with spinal shock or neurogenic shock with neurologic deficits. Brady-arrhythmias and loss of sympathetic tone may be seen within 30 min of injury and may persist for up to 6 weeks. Avoidance of hypotension in these patients is critical to prevent secondary ischemic insults to the spinal cord, that may worsen any preexisting neurologic deficits.

Musculoskeletal Trauma

While the majority of musculoskeletal trauma is not considered life threatening and the management of orthopedic injuries is beyond the scope of this chapter, trauma teams should have fundamental knowledge of some orthopedic emergencies. Femur fractures may be life threatening secondary to massive blood loss in the thigh from the bone vascular complexes, surrounding musculature, and major vasculature near the fracture. Early discussion with an orthopedic surgeon is imperative to ensure early stabilization and operative repair.

As with all fractures, if reduction or manipulation is attempted, it is necessary to obtain a distal neurovascular exam before and after intervention. If an urgent or emergent reduction is necessary due to concern for concomitant vascular pathology with absent distal pulses or altered neurologic examination, repeated examinations should be undertaken and the findings closely monitored. Arterial indices should be monitored in any major peripheral vascular injury associated with long bone fractures. Angiography may be performed if there is concern for vascular compromise.

Open fractures necessitate administration of prophylactic antibiotics. Most often cefazolin is sufficient, though more extensive injuries or those with overt contamination may require alternative regimens [22]. Tetanus immunization status should be assessed and the vaccine administered if vaccination status is unknown.

Thermal Injuries

Patients with severe burns are best cared for at designated burn treatment centers. Treatment depends on the severity and extent of the body burned. Total body surface area (TBSA) burned is measured in percentage points according to the Lund–Browder chart (the "Rule of Nines"). Only second- and third-degree burns are included in the TBSA calculation. Children and the elderly, due to their more friable skin, are at increased risk of severe burn injuries.

Patients with burns ≥20% TBSA require early and aggressive fluid replacement. Either 2 mL (modified Brooke formula) or 4 mL (Parkland formula) per kilogram of body weight per % burned TBSA of isotonic crystalloid (e.g., lactated Ringer's solution) should be administered in the first 24 h, with the first half of the volume administered in the first 8 h since injury and the second half administered in the following 16 h. Recent ATLS® guidelines recommend closely monitoring urine output and adjusting the infusion rate to achieve a urine output of 0.5–1.0 mL/kg/h [1]. Care should be taken to avoid excessive fluid and blood administration, as fluid overload can cause right heart failure, pulmonary edema, pleural effusions and multiple compartment syndrome (i.e., compartment syndromes of the abdomen or extremities). Small children and infants should receive dextrose in their resuscitation fluids because their risk for hypoglycemia is high.

Burn Shock

Blood loss is also common in patients with massive burns. Serial hemoglobin and hematocrit levels should be obtained and blood transfused accordingly to a hemoglobin goal of 7.0 g/dL unless prior coronary artery disease or active acute coronary syndrome are present, in which case a hemoglobin goal of 8.0 g/dL may be indicated.

Though burns are often the only external manifestation of thermal injury, care should be taken to evaluate the airway early. Smoke inhalation and caustic material ingestion often accompany burns, and may predispose the patient to progressive airway swelling and impending respiratory distress. Singed nasal hairs and oropharyngeal deposits of soot are predictors that deeper penetration of smoke may have occurred. Tachypnea, stridor, and altered mental status are later signs of airway compromise that may necessitate endotracheal intubation. Early assessment with laryngoscopy, pharyngoscopy, bronchoscopy, and esophagoscopy may be required for baseline anatomical assessment and evaluation.

Succinylcholine curarization more than 24 h after burn injury can cause fatal hyperkalemia, so other curarizing agents should be preferred, if necessary. Carboxyhemoglobinemia may occur in patients who have inhaled smoke and may cause falsely elevated readings from the pulse oximeter. Oxygenation should therefore be evaluated with arterial blood gases or co-oximetry. Hyperbaric oxygen therapy is an effective therapy for clinically significant carboxyhemoglobinemia.

Early transport to tertiary burn centers has demonstrated a mortality benefit in this population. It is imperative to continue active reassessment of these patients during the initial 72 h of resuscitation to identify the need for early debridement and escharotomies.

Electrical Injuries

Electrical shocks and lightning strikes may induce cardiac arrhythmias. Ventricular fibrillation is a life-threatening arrhythmia that may be encountered by emergency medical services in the prehospital environment. Arrhythmias should be treated in accordance with Advanced Cardiac Life Support guidelines (acls.net/aclsalg). Patients should have an ECG performed on admission and should receive continuous cardiac monitoring in case delayed arrhythmias develop. Electrical damage may induce cardiomyocyte damage, so any patients with any chest pain should have troponin levels evaluated.

Pediatric Trauma

Trauma is the leading cause of death and disability for children in the United States. As of 2020, firearm-related injury surpassed motor vehicle accidents as the principal cause of death in children, according to the Centers for Disease Control [23]. Other causes of death in decreasing order include drug overdose/poisoning, suffocation, drowning, and burns. In Europe, the leading cause of death remains motor vehicle accidents [24]. The majority of homicides in infants (children <1 year of age) is accounted for by non-accidental trauma (battered child syndrome). Signs include multiple subdural hemorrhages, metaphyseal long bone fracture, posterior rib fractures, and bilateral retinal hemorrhages. Even treatable, reversible cases may require formal legal reporting, depending on institutional rules and local legislation.

Ventilatory Assistance and Shock

The care of infants and children following trauma demands a multidisciplinary team approach to address both the medical and psychological sequelae of trauma and to offer the child the best chances for a quick recovery. The most common reason for unsuccessful resuscitation of the pediatric patient includes failure to secure the airway and manage ventilation, as well as failure to recognize and treat intracranial and intra-abdominal hemorrhage. When evaluating a young child, the use of a Broselow tape or ribbon (a length-based, color-coded resuscitation aid) is endorsed by the Pediatric Advanced Life Support, even though controversies emerge, particularly concerning overweight and obese children. Criticisms notwithstanding, it contributes to standardize initial care, minimize medication errors, and assist with properly sized equipment selection.

If intravenous access is not obtained in an emergent situation, intraosseous access is indicated, with the anteromedial proximal tibia and distal femur as the preferred sites.

Central Nervous System Trauma

The relatively large size of a child's head compared with the rest of their body increases angular momentum and predisposes them to trauma of the head and cervical spine. Bones in pediatric patients are not yet fully calcified, meaning that bony manifestations of trauma may not be apparent, even when severe blunt trauma may have occurred. Care should be taken to perform a thorough evaluation of intracranial, intrathoracic, and intra-abdominal structures when the mechanism of injury indicates possible lesions, even if there is no associated overlying bony deformity. However exposure of the child to radiation (e.g., for a CT scan) should be limited wherever possible according to the As Low As Reasonably Achievable (ALARA) guidelines [25].

The spleen is the most commonly injured organ following blunt abdominal trauma, followed by the liver. Small bowel perforations at the ligament of Treitz are more common in children, as are bladder rupture injuries (due to the shallow depth of the pediatric pelvis).

Endotracheal Intubation

Decreased pulmonary functional residual capacity is seen in children, predisposing them to rapid desaturation when apnea is induced. Thus, adequate pre-oxygenation should be undertaken prior to endotracheal intubation whenever possible. A long, floppy epiglottis is present in young children, and a straight (e.g., Miller) blade may be preferred over a curved (e.g., Macintosh) blade for direct laryngoscopy. Surgical cricothyroidotomy is rarely indicated in children <12 years of age, due to inability to palpate the cricothyroid membrane. If tension pneumothorax is suspected, needle decompression should be accomplished at the second intercostal space in the mid-clavicular line.

Challenges in Diagnosis of Shock

Children have increased physiologic reserve, and hypotension may not manifest until 30% or more of the total blood volume has been lost. Progression from tachycardia to bradycardia often accompanies hypotension in children. The lower limit of normal Systolic Blood Pressure in children may be obtained with the following formula: Lowest acceptable SBP = (2 * age in years) + 70 mmHg. In the hypotensive child, fluid resuscitation with 20 mL/kg of isotonic crystalloid is indicated prior to initiation of transfusion of 10–20 mL/kg of balanced ratios of PRBCs, FFP, and platelets.

Transfer to a designated pediatric trauma center is critical after initial stabilization. Awaiting transfer, consultation with pediatric subspecialists will aid resuscitative efforts. It is important to recognize that infants and children have unique physiology that requires an in-depth understanding, and may inform a different approach to trauma care.

Geriatric Trauma

Though the mechanisms of injury are similar across age groups, the mortality of these injuries in geriatric patients is higher. This may be due to improper triage, senescence of organ systems, and a higher incidence of pre-existing medical conditions at the time of injury [26]. The most common mechanisms of trauma in the geriatric population include falls, motor vehicle accidents, burns, and penetrating injuries [27]. Those with hepatic cirrhosis, coagulopathy, chronic obstructive pulmonary disease, ischemic heart disease, or diabetes mellitus are more likely to die. Traumatic injuries due to another medical condition (i.e., motor vehicle accident after myocardial infarction or seizure) should be considered during initial presentation and workup.

Brain Trauma

Geriatric patients are at increased risk for traumatic brain injury and its associated morbidity and mortality due to their pre-existing conditions (e.g., cognitive deficits) and prescription drugs (sleep medication, anticoagulants, and/or antiplatelet agents). Furthermore, it may be difficult to distinguish between pre-existing dementia and a new-onset neurologic deficit; presence of family members at the bedside may assist clinicians in determining changes in mental status.

Reversal of Anticoagulants

This is a novel and quickly evolving field and is indicated in the instance of life-threatening bleeding. Warfarin may be reversed with administration of fresh frozen plasma, vitamin K, prothrombin complex concentrate (Kcentra, CSL Behring), or recombinant Factor VIIa. The Factor Xa inhibitors apixaban (Eliquis, Bristol Myers Squibb), rivaroxaban (Xarelto, Bayer), and edoxaban (Lixiana, Savaysa, Daiichi Sankyo) may be reversed with andexanet alfa (AndexXa, Astra Zeneca) or with a four-factor prothrombin complex concentrate. The direct thrombin inhibitor dabigatran (Pradaxa, Boehringer Ingelheim) may be reversed with idarucizumab (Praxbind, Boehringer Ingelheim). Low molecular weight heparin (enoxaparin, Lovenox, Winthrop) and unfractionated heparin can be reversed with well-known protamine sulfate.

Bones and Joints

Arthritic changes may complicate airway management due to restricted motion of the cervical spine. Rib fractures are more common due to age-related osteopenia and may be associated with splinting on respiration, leading to increased risk for pneumonia, atelectasis, and mortality. The risk of pneumonia and mortality increases for each additional rib fractured [1]. Pelvic fractures in the elderly are associated with a four-fold increase in mortality compared to similar injuries in younger patients.

Mandatory Legal Reporting

As may be noted in other vulnerable populations such as pregnant patients and children, maltreatment of aged persons should be considered. When history and clinical findings are suggestive of abuse or neglect, an expeditious social work consultation should be undertaken and the authorities contacted.

Ideal patient-centered care may be accomplished by having early goals of care discussions with both the patient and their family. Because age is such an important risk factor for morbidity and mortality following trauma, these conversations provide a useful framework for structuring future discussions regarding aggressive en of life care, should a patient's clinical condition worsen. A preliminary exchange regarding social, familial, cultural, and religious beliefs and priorities should convert potentially painful questions into less challenging ones.

Trauma in Pregnancy

Approximately 6–8% of pregnant patients will experience a traumatic injury, most commonly from motor vehicle incidents [28]. It is important to recognize that up to 8% of pregnant patients presenting with blunt trauma may be victims of domestic violence instead [29]. The obstetric team is ideally present for admission of any pregnant patient to the trauma bay to monitor both the parturient and fetus and to perform an expedient delivery if emergently indicated. Fetal heart tones should be continuously monitored after 20–24 weeks of gestation. It is important to note that pregnancy causes relevant anatomic and physiologic changes that can inform care (Table 11.4).

IV access should be obtained above the diaphragm in case of caval compression by the gravid uterus, and patients placed in a modified left lateral decubitus position to offload the vena cava and optimize venous return. The risk of gastroesophageal reflux and aspiration is increased in pregnant patients in the second and third trimesters, so each patient should be assumed to have a full stomach and the airway managed with RSII as described earlier in this chapter. Fluid retention during pregnancy may distend the oropharyngeal tissues and displace airway structures from their normal location, complicating endotracheal intubation. Video laryngoscopy is the preferred method for airway management.

Pregnant patients presenting in cardiac arrest should have perimortem cesarean delivery performed within 5–10 min, which may improve both maternal and fetal

Table 11.4 Selected anatomic, physiologic, and laboratory changes of pregnancy [28–31]

Anatomic and physiologic changes of pregnancy
Increased
Heart rate and cardiac output
Mucosal engorgement of nasal and oral cavities
Minute ventilation (mostly from increased from tidal volume)
Oxygen consumption
Plasma volume
Uterine size (fundal height reaches umbilicus at 20 weeks gestation)
Decreased
Functional residual capacity
Lower esophageal sphincter pressure
Rate of gastric emptying (principally during labor)
Systemic vascular resistance and blood pressure (starting in second trimester)

Normal laboratory values (**non-pregnant**)	Parameter	Normal laboratory values (**pregnant**)
22–26	Bicarbonate (mmol/L)	20
0.6–1.2	Creatinine (mg/dL)	0.4–0.7
12–16	Hemoglobin (g/dL)	11
40	$PaCO_2$ (mmHg)	30
7.40	pH	7.44

survival [30, 31]. Perimortem cesarean delivery should be performed at the site of the arrest, because transport to an operating room comes at the cost of time and high-quality resuscitative efforts. There is no evidence that any medication used during ACLS is teratogenic or harmful to the fetus. Therefore, especially in traumatic arrest, the ATLS® approach to resuscitation in conjunction with ACLS should not be altered.

Amniotic fluid embolism is a life-threatening complication that involves the entry of amniotic fluid into the maternal vascular space and is associated with disseminated intravascular coagulation.

Immunoglobulin therapy (Rho[D] immune globulin, several manufacturers) should be given to all Rh-negative parturients (intramuscular or intravenous route, depending on product) unless the injury site is remote from the abdomen and isolated. As mentioned above, many parturients fall victim to physical abuse, so this should be considered in the right clinical context.

Transferring to Definitive Care

Trauma patients benefit from receiving care at trauma centers for a variety of reasons. If transfer to a designated trauma center is being considered, early consultation with the receiving trauma center should be initiated to help guide further management, imaging, and transfer priorities. It should also be noted that tertiary referral centers are frequently at maximum capacity, which may also delay transport. Studies demonstrate that a significant portion of trauma patients undergo CT imaging prior to transport, which has been shown to lead to lengthy delays in definitive care [32]. There occurs a high rate of repeat CT scans at receiving facilities, which is associated with increased healthcare costs and radiation exposure for patients [33, 34].

All available records, laboratory data, and imaging obtained at the initial hospital should be transmitted to the receiving institution for review. Ideally, this occurs electronically during the initial transfer request phone call. When giving handoff to another team, a systematic approach or framework such as the SBAR protocol (situation, background, assessment, and recommendation) may be helpful in maintaining brevity in communication, yet ensuring that vital information has been relayed to formulate an effective care plan.

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