Assessment and Treatment of the Trauma Patient in Shock

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INTRODUCTION

The presentation of a critically ill trauma patient demands the quick response and diagnostic savvy of an emergency medicine–trained physician. As with all critically ill or injured patients, the physician should begin an evaluation by addressing airway, breathing, and circulation (ABCs), after which further assessment of a patient’s injuries can occur. Advanced Trauma Life Support guidelines establish a specific sequence of events when examining a trauma patient, including the ABCs and primary and secondary surveys. These sequences should be both familiar and routine to every emergency physician.

Trauma patients often present with signs and symptoms of shock, with or without obvious cause. Patients with polytrauma may have more than 1 injury contributing to hemodynamic instability, which may further complicate the picture when attempting to determine the cause of shock.

Disclosure: None.

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http://dx.doi.org/10.1016/j.emc.2014.07.004
0733-8627/14/$ – see front matter © 2014 Elsevier Inc. All rights reserved.

KEYWORDS

- Trauma patient
- Shock
- Nonoperative management
- Solid organ injury

KEY POINTS

- High-volume crystalloid resuscitation is associated with increased length of stay, ICU and ventilator days, and organ failure and infection rates.
- Rapid evaluation of a hemodynamically unstable trauma patient is vital to diagnosis and treatment of the cause of shock.
- CT scanning should be used liberally in trauma patients to effect decreased mortality.
- Nonoperative management (NOM) and catheter-based interventions are becoming the standard of care in appropriately selected patients with solid organ injuries.
RESUSCITATION

In spite of historic recommendations to administer 1 to 2 L of fluid for resuscitation, recent literature has suggested that high-volume crystalloid resuscitation after injury is associated with significant morbidity, including increased ventilator days, longer ICU and hospital length of stay, development of acute respiratory distress syndrome, and multisystem organ failure and increased infection rates. Crystalloid infusion, in the setting on ongoing hemorrhage, promotes bleeding and hemodilution, and perpetuates acidosis, hypothermia, and coagulopathy. This belief has led many centers to use blood products earlier in resuscitation in patients with ongoing hemorrhage. Recent data have suggested benefit from transfusion of red blood cells (RBCs), plasma, and platelets in even ratios. This practice, often referred to as “1-1-1,” has become standard practice in many trauma centers and is currently being studied in a large multicenter prospective trial.

For patients who require resuscitation but do not have ongoing hemorrhage, the ideal fluid for resuscitation remains unknown. Normal saline and lactated Ringer solutions have been the traditional choices. Aggressive resuscitation with crystalloid solutions, however, has been associated with negative clinical outcomes in blunt trauma patients. When comparing crystalloid and colloid resuscitation, colloids have been associated with a trend toward increased mortality in trauma patients. When the study excluded patients with traumatic brain injury, however, there was no difference in mortality. PlasmaLyte, a crystalloid balance solution, has also been used as a resuscitative fluid. With several different formulations, it is similar to plasma and has been termed, physiologic solution or balanced solution. PlasmaLyte has some advantages over Ringer lactate and normal saline in that it corrects both volume and electrolyte deficits without causing a hyperchloremic acidosis. Despite these advantages, studies evaluating its use after injury have shown no evidence of superiority to other crystalloids for the management of traumatic hypovolemia.

Hypertonic saline has also been used as a resuscitative fluid. Due to its oncotic quality, it augments perfusion through volume expansion. This is beneficial for patients with traumatic brain injury to help decrease elevated intracranial pressure. Additionally, animal models have shown that hypertonic saline helps minimize the inflammatory response after traumatic and hemorrhagic shock. Unfortunately, no clinical trial has demonstrated benefit for the use of hypertonic saline after injury, except possibly for patients with traumatic brain injury (see the neurotrauma chapter elsewhere in this issue).

Permissive hypotension is the practice of targeting a lower systolic blood pressure in the setting of hemorrhagic shock. The landmark study by Bickell and colleagues demonstrated a survival benefit for patients with penetrating torso trauma who received delayed (once in the operating room) resuscitation compared with those who received fluid administration in the field. Due to significant differences in injury and mechanism patterns, subsequent studies have not been able to duplicate this work. Despite this, permissive hypotension in the setting of hemorrhage, specifically penetrating torso trauma, is practiced at many high-volume trauma centers. A specific blood pressure has not been elucidated in the literature; however, based on the current available studies, a systolic blood pressure goal of 70 to 100 mm Hg is reasonable.

ASSESSMENT OF BODY COMPARTMENTS

Head/Neck

Examination

Patients who have sustained head trauma can present with a mental status ranging from severely obtunded and unresponsive to essentially normal, depending on the
severity of the brain injury. Patients presenting with head or facial injuries, concerning mechanisms of injury, or any complaints of neck pain should have a hard cervical collar in place until the cervical spine has been appropriately examined, both on physical and radiologic examination, and clinically cleared when able. Clinical clearance of the cervical spine has been studied by several groups. Specifically, the NEXUS criteria and the Canadian Cervical Spine Rule are the most well known. The criteria require that a patient cannot have any of the following: distracting injury, evidence of intoxication, midline cervical spine tenderness on palpation, or altered level of consciousness. If none of these are present, the physician can clear the cervical spine without obtaining imagining. The presence of 1 or more of these criteria dictates the need for imaging prior to clinical clearance. The Canadian Cervical Spine Rule includes patients who are hemodynamically stable, alert and oriented, and have a dangerous mechanism of injury in addition to several other inclusion and exclusion criteria to determine the need for cervical spine imaging.

A full neurologic examination, including determination of a patient’s presenting Glasgow Coma Scale (GCS), should be performed in every trauma patient. Neurologic deficit patterns can suggest specific injuries and guide therapy. Injuries to the brain and spine can result in vital signs that are indicative of shock but often are associated with specific examination findings suggestive of neurologic or spinal shock rather than hemorrhagic. Neurogenic shock, which is a true circulatory problem, is considered a form of distributive, or warm, shock secondary to the vasodilation associated with the loss of vascular sympathetic tone after spinal cord injury. It is rare to see the classic findings of hypotension and bradycardia of neurogenic shock but, if suspected, these manifestations should be treated aggressively. Spinal shock is a presentation of acute spinal cord injury occurring within the first 24 hours and is usually a pattern of symptoms that include total loss of reflexes below the level of injury; flaccid paralysis, including loss of rectal tone; and complete loss of sensation. Spinal shock is often accompanied by autonomic dysfunction but is not exclusively a hemodynamic phenomenon.

Facial fractures, scalp lacerations, and hematomas can be significant sources of external hemorrhage; hemostasis should be achieved as quickly as possible. Internally, subarachnoid, subdural, and epidural hematomas are imperative diagnoses to make but do not in isolation cause hemorrhagic shock.

**Imaging**

CT scans of the head and cervical spine have become routine in trauma patients with abnormal mental status, intoxication, or evidence of laterализing signs on examination. Patients with a GCS of 13 to 15 can be evaluated, however, using the Canadian CT Head Rule (CCHR) or the New Orleans Criteria (NOC) to determine the need for CT scan (Boxes 1 and 2). In a 2012 study comparing the 2 rules for mild traumatic brain injury, researchers found a similar sensitivity but an increased specificity in the use of the CCHR (35% compared with 9.9% in the NOC) in diagnosing an intracranial lesion on CT scan, a clinically significant brain injury, or the requirement for neurosurgical evaluation.

**Chest**

**Examination**

Patients with thoracic trauma and hypotension should be immediately assessed for external signs of injury, including evidence of penetrating wounds, tracheal deviation, jugular venous distention, or flail chest/paradoxic breathing patterns. Diminished or absent breath sounds should prompt the urgent placement of a thoracostomy tube,
especially in a patient with unstable hemodynamics, for the evacuation of a potential tension pneumothorax or hemothorax. Open wounds should be covered to prevent exacerbation of a pneumothorax until a chest tube can be placed. The presence of jugular venous distention, distant cardiac sounds, and hypotension in the setting of blunt chest trauma should raise concern for tamponade and should be assessed as part of the focused assessment with sonography for trauma (FAST) examination. The physician should proceed cautiously when considering endotracheal intubation of patients with evidence of tamponade. Even in a stable patient with early signs of tamponade, sedation and positive pressure ventilation can cause significant hemodynamic instability and cardiac arrest by compromising venous return to the heart. Treatment of the tamponade prior to securing an airway can potentially avert cardiovascular collapse.

The management of patients with chest trauma varies depending on the mechanism. Blunt thoracic trauma and penetrating trauma can both present with significant hemodynamic instability for similar reasons but by different mechanisms. Both blunt and penetrating trauma can lead to pneumothorax, hemothorax, or tamponade. Resuscitative thoracotomy should be considered in specific patients. Traditionally, it has been used primarily in the setting of penetrating chest trauma, but over the past 2 decades it has been used more often in the setting of blunt trauma as well. Indications include witnessed penetrating trauma with less than 15 minutes of prehospital cardiopulmonary resuscitation (CPR) or witnessed blunt trauma with less than 5 minutes of

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<td>Greater than 2 episodes of vomiting</td>
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<td>Age greater than 65 years</td>
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prehospital CPR. Other indications include severe, persistent hypotension after injury likely due to tamponade, hemorrhage, or air embolism. In 2011, The Western Trauma Association published a prospective study evaluating the survival rate of patients with both blunt and penetrating injuries having received thoracotomy. The investigators concluded that resuscitative thoracotomy should be considered futile when prehospital CPR exceeds 10 minutes without response in patients with blunt trauma and 15 minutes in patients with penetrating injuries. Additionally, if asystole is the presenting cardiac rhythm and there are no clear signs of tamponade, thoracotomy should not be performed.25

**Imaging**

A plain chest radiograph for both blunt and penetrating chest trauma should be done as urgently as possible to assess for hemothorax, pneumothorax-associated rib fractures, or an abnormal mediastinal contour. At a minimum, this is a screening examination for an unstable patient. CT evaluation of true, penetrating trauma should be performed in every setting when patients are stable. Unstable patients with penetrating injuries should have surgical exploration.

In the vast majority of patients with blunt chest trauma, a normal chest radiograph predicts an unremarkable chest CT (82%). In a recent study, injuries diagnosed on CT scan after negative chest radiograph included rib fractures, minor pulmonary contusions, and occult pneumothoraces but did not result in changes to management. Brink and colleagues have proposed parameters that can be used to determine the need for chest CT in blunt trauma patients. These parameters include abnormal chest examination; age greater than 55; abnormal radiograph of the chest, spine, or pelvis; abnormalities on the FAST examination; and laboratory abnormalities, including a hemoglobin less than 6 mmol/L or a base deficit greater than 3 mmol/L. Using these parameters, the investigators found that less than 2% of clinically significant injuries are missed. The presence of a normal mediastinal contour does not rule out the possibility of aortic injury. Demetriades demonstrated that 45% of patients with CT diagnosis of aortic rupture had normal chest radiographs. These findings suggest that despite a normal chest radiograph, patients with high-risk mechanisms, including high-speed deceleration, should undergo CT angiography of the chest. Over the past decade, a shift in diagnosis of aortic injury has occurred. Although transesophageal echocardiogram and aortography have been historically the gold standard for diagnosis, they are rarely used since CT angiography has undergone improvements in quality and availability. More than 93% of aortic injuries are diagnosed based on CT angiography.

**Abdomen**

**Examination**

Similar to thoracic trauma, abdominal trauma results from blunt or penetrating mechanisms, and has a broad differential. Examining the abdomen for distention or outward signs of trauma, including a seat belt sign or penetrating wounds, should be done quickly. Palpation of the abdomen for tenderness or rigidity can be helpful if a patient is able to participate in the examination. Obvious extrusion of mesentery or evisceration of hollow viscous indicates peritoneal violation and the need for operative intervention.

Establishing pelvic stability through examination and bedside pelvic radiograph assists in rapid diagnosis of pelvic fractures contributing to hemorrhagic shock. A pelvic binder should be placed in the setting of likely or known pelvic fractures associated with hemodynamic instability and should remain in place until definitive stabilization is affected. Specifically, anterior-posterior compression pelvic fractures, or open book fractures, are the most responsive to external pelvic stabilization. Lateral
compression fractures are not often associated with hemodynamic instability and in this case caution should be exercised when placing a pelvic binder.

**Imaging**

Historically, the use of diagnostic peritoneal lavage (DPL) was used to evaluate for intraperitoneal blood after trauma, but over the past 2 decades, DPL has been largely replaced with bedside ultrasound and the FAST examination. An abdominal examination in conjunction with a FAST examination should prove a starting place to determine the acute need for operative intervention in a trauma patient. Hemodynamically unstable patients with a positive FAST examination should be considered for exploratory laparotomy. Many studies exist that support the efficacy of the FAST examination in bedside diagnosis of intraperitoneal free fluid, although there are several limiting factors to their reliability, including operator skills and patient body habitus. The FAST examination can be performed quickly at the bedside, preventing an unstable patient from leaving the emergency department to be evaluated in the CT scanner.

A hemodynamically unstable patient with penetrating trauma to the abdomen should be taken to an operating room for exploration. In recent years, there has been a shift in management of hemodynamically stable patients with penetrating trauma to the abdomen. CT scan with triple contrast is both sensitive and specific in evaluating for peritoneal violation and viscous injury to determine the necessity of operative management.

The utility of CT scan in the setting of a patient with blunt abdominal trauma has also been challenged in the past decade, with many proposed diagnostic algorithms. In 2009, a prediction rule, including GCS less than 14, abdominal tenderness or costal margin tenderness, hematuria (>25 RBCs/high-power field), femur fracture, abnormal chest radiograph, and a hematocrit less than 30%, showed 96% sensitivity for any intra-abdominal injury, particularly if it required acute intervention. Overall, however, there is no general consensus about who can safely be monitored and who requires an abdominal CT scan.

The need for oral contrast in the assessment for hollow viscous injury in the setting of blunt abdominal trauma has been questioned. Stuhlfaut and colleagues, in 2004, determined that oral contrast was not necessary for the successful and accurate diagnosis of bowel and mesenteric injury. A prospective randomized study evaluating CT diagnosis of viscous injury in blunt abdominal trauma using oral contrast suggests there is no difference between oral contrast and only intravenous contrast. The investigators of this study also observe that it is unlikely that oral contrast is given enough time to transit the intestinal tract after administration and before CT scanning is performed to be of benefit when assessing for hollow viscous injury.

**Compartments**

**Examination**

In a patient with shock, it may be difficult to appreciate pulses in all extremities as a result of low systemic blood pressure. The use of Doppler may be required. Determining the equality of pulses in extremities is important and differences should be concerning for arterial injury. In the evaluation of suspected vascular injury, the presence of hard signs indicates the absolute need for operative investigation and repair (Box 3). Soft signs (Box 4) can be equally concerning to a physician. In the presence of soft signs and a suspicion of vascular injury, the use of the ankle-brachial index (ABI) can be useful. An ABI of less than or equal to 0.9 should raise suspicion for vascular injury and warrants additional imaging or operative evaluation. An ABI of less than 0.9 has been shown to have a specificity of approximately 97% for identifying arterial
Compartment syndrome can have devastating effects, including tissue necrosis and rhabdomyolysis; palpation of a tense compartment should trigger direct measurement of compartment pressure. Pain, especially with passive range of motion, is often the initial symptom of compartment syndrome and is frequently out of proportion to what is expected based on physical examination findings. Parasthesias are also common and an early sign. Classic findings of pallor, paralysis, and pulselessness are late findings.

Hemodynamic instability and shock are occasionally related to blood loss due to extremity trauma. Usually, if blood loss in the setting of extremity injury is significant enough to create hemodynamic compromise, partial or total amputation or arterial injury is often appreciable on examination. In these settings, emergent control of bleeding can occur through direct pressure on a bleeding artery or through the application of tourniquets while preparing for operative intervention and definitive control of bleeding and injury.

The use of tourniquets has been extensively studied in the military arena. Up to 20% of combat injuries involve severe trauma to the limb(s), which can result in rapid exsanguination. Tourniquet application has been shown highly effective in both upper and lower extremity trauma with little associated complication. It has been shown an expeditious maneuver that can be performed by even inexperienced personnel with high success rates and improved outcomes.

**Imaging**
Generally, imaging of extremity injuries should be done with plain radiographs. If concern exists that vascular injury has also occurred in the setting of fracture or other traumatic injury, CT angiography can be performed. Intraoperative angiography of the extremities can be accomplished in most trauma centers and may be more appropriate in patients who require emergent operative intervention for other injuries. Inaba and colleagues found that CT angiography was both 100% sensitive and specific for clinically significant (requiring operative repair) arterial injuries and should be used in patients with soft signs of vascular injury to potentially avoid unnecessary operative exploration.

**Box 3**  
**Hard signs of vascular injury**
- Evidence of external bleeding
- Hematoma—rapidly expanding
- Evidence of arterial occlusion (pain, pallor, pulselessness, parasthesias, or paralysis)
- Palpable thrill
- Bruit

**Box 4**  
**Soft signs of vascular injury**
- Proximity of penetrating or blunt injury to an artery
- Presence of hematoma over an artery
- Arterial bleeding at the scene or during transport
- Neurologic deficit in the distribution of a named artery
GENERAL TRENDS IN TRAUMA IMAGING

There has been an overall shift in the general imaging practices in trauma care over the past decade. Significant literature has focused on the liberalization of CT scanning in trauma patients whereas the general medicine focus has shifted toward minimizing unnecessary radiation exposure to patients. In patients with polytrauma, whole-body CT (WBCT), including imaging of the head, cervical spine, chest, abdomen, and pelvis, has been shown both cost effective and demonstrating a statistically significant survival benefit when performed early in a patient’s resuscitation. Majeed and colleagues noted that 74% of their management plans changed based on WBCT and the cost savings were noted to occur primarily as a result of preventing unnecessary admissions for observation. Also, as a result of the increased WBCT scanning in trauma patients, there has been a significant increase in the number of incidental findings, many of which did not change the evaluation for the presenting problem, but up to 10% of which required urgent follow-up. Recent studies that have evaluated this unintended result of WBCT report upwards of 40% to 45% of patients undergoing CT scan are found to have an unrelated incidental finding.

**Spleen**

The spleen is the most commonly injured solid organ in adults after blunt trauma. It can occur in isolation or with other injuries, both intra- and extra-abdominal. The Organ Injury Scaling Committee of the American Association for the Surgery of Trauma describes a graded scale, from 1 to 5, based on radiographic findings on CT or at time of laparotomy. With the development of multidetector CT technology, the grading system of splenic injuries has evolved. Some investigators have sub-classified grade IV injuries to differentiate between those with intraparenchymal bleeding, without intraperitoneal bleeding (IVa), and with intraperitoneal bleeding (IVb).

Traditionally injuries to the spleen were managed surgically with splenectomy; however, with the discovery of overwhelming postsplenectomy sepsis (OPSS) and the desire to preserve splenic immune function, paradigms in management began to change. The incidence of OPSS is believed to be 0.05% to 2% of patients with splenectomy. Despite this low rate, surgeons began to attempt splenic salvage. Techniques included partial splenectomy or a splenorrhaphy. It was not until the late 1960s that NOM was first described in the pediatric population. Since that time, NOM and the use of angiography has grown significantly. There are many advantages to NOM, including shorter hospital length of stay, decreased hospital costs, decreased intra-abdominal complication rates, and decreased blood transfusions.

The use of CT scan has greatly changed the management of patients with splenic injuries. Over time, with the improvement in CT technology, the information provided has significantly increased. CT has been shown highly accurate (98%) in diagnosing acute splenic injuries. Additionally, angiography can be used to diagnose and treat traumatic splenic vascular injuries with high rates of success. As a result, the management of the splenic injuries continues to evolve and change. A 1991 study by Sclafani and colleagues evaluated hemodynamically stable patients with a splenic injury diagnosed using first-generation CT scan technology. All patients subsequently had angiography performed. Those patients demonstrating active extravasation (AE) on angiography had proximal splenic artery embolization whereas those without AE had simple observation. The investigators were able to avoid laparotomy in 94% of the patients selected for NOM. In 2005, Haan and colleagues looked at a 5-year experience in a high-volume trauma center using splenic embolization. The investigators demonstrated that patients selected for observation alone with serial
hematocrits (average grade of injury approximately 2) had 100% salvage rate. Patients who had angiography and embolization (average grade of injury approximately 3) had a 90% success rate of NOM. The investigators noted that as the grade of injury increased, the success rate of NOM declined. The investigators concluded, however, that significant hemoperitoneum, AE, and pseudoaneurysm on admission CT were not predictive of NOM failure, which contradicted the EAST (Eastern Association for the Surgery of Trauma) multi-institutional trial.46 Historically, age over 55 years has been suggested as a risk factor for failure of NOM of splenic injuries and considered a contraindication to NOM.60–62 Other studies have shown, however, that age alone should not be considered a contraindication and that outcomes are similar between the age groups.63–65

The amount of published literature regarding NOM of the spleen continues to grow and evolve as technology and newer treatment techniques are developed. As such, no 2 institutions have the same treatment algorithm. Currently, the authors’ management algorithm for stable blunt splenic injuries is as follows:

- Grade I and II splenic injuries are managed with observation, serial complete blood counts, and serial abdominal examinations.
- Grade III injuries, in addition to serial complete blood counts and abdominal examinations, have a nonemergent angiography performed (nonemergent is defined as during the daytime hours).
- Grade IV and V injuries have an emergent angiography performed.

Those patients who have angiography performed, with or without embolization, have a repeat CT performed at 48 to 72 hours after injury. If repeat imaging is stable and patients are otherwise clinically stable, they are discharged. There is considerable debate over the need for repeat imaging after blunt splenic injuries. Lower-grade injuries (I and II) probably do not need repeat imaging.66 Early studies showed a mean of 2.7 days from admission to failure for those patients who had angiography without embolization and 1 day for those who had embolization.67 Davis and colleagues68 demonstrated approximately two-thirds of pseudoaneurysms were present on repeat imaging on day 3 that were not present on the initial CT scan thus advocating serial CT scan.

Liver

As with the spleen, injuries to the liver can occur after both blunt and penetrating trauma. Additionally, a grading system based on injury severity has been developed.48 Traditionally, operative intervention was the accepted management strategy for blunt liver injury; however, many injuries were found minor without active bleeding.69–72 Based on these findings and that NOM of liver injuries in pediatric patients had very high success rates, the techniques for managing blunt liver injuries began to change.69,73–76 As a result, there is a growing body of literature supporting the use on NOM for liver injuries with high rates of success.70,77–79

Current diagnostic strategies for liver injuries are similar to those of the spleen. DPL and FAST are bedside procedures that can be rapidly performed; however, they do not specifically identify the liver as the source of hemorrhage. CT remains the imaging modality of choice for liver injuries. As with the spleen, as CT technology evolves so does the detail of information provided. This constant evolution of technology creates ever-changing treatment algorithms. Despite new technology, any hemodynamically unstable patient should proceed directly to the operating room. Additionally, any patients with an alternate indication for laparotomy, including peritonitis, should proceed directly for surgical exploration.80,81
For those patients who do not have an indication for immediate operative intervention, NOM has become the standard of care for patients who are hemodynamically stable.81–85 Traditional risk factors thought related to failure of NOM included grade of injury, simultaneous traumatic brain injury, amount of hemoperitoneum, age greater than 55 years, transfusion requirements, or blush on CT scan.77,82,86 Recent literature, however, questions these risk factors and currently they are not believed absolute contraindications to attempting NOM in hemodynamically stable patients with a liver injury.65,82,87,88

Low-grade injuries (I and II) usually can be managed with simple observation and serial laboratory evaluation. A patient’s clinical scenario should dictate any further intervention surgical or repeat imaging. Higher-grade injuries without AE, as demonstrated by blush on CT scan, can also typically be managed with simple observation with serial laboratory and clinical examinations. Injuries that demonstrate AE should be considered for angiographic evaluation.89 Angiographic embolization can be helpful in the NOM treatment of liver injury,73 and several studies have demonstrated its benefit in controlling hemorrhage.90,91 Despite these reports, its use remains controversial.82 Studies have demonstrated that angioembolization of liver injuries is associated with several complications, including major hepatic necrosis, liver abscess, gall bladder necrosis/ischemia, bile leak92–94 vessel damage at site of arterial cannulation, and renal dysfunction-related contrast injection.82

Kidney

The kidney, like the spleen and the liver, has a grading system of injury.48 Renal injuries occur in up to 3% of all trauma patients and are as high as 10% for those with abdominal trauma.95 Unlike other intra-abdominal injuries, a renal (genitourinary) injury can be quickly suspected based on a urinalysis. Gross hematuria increases the likelihood of injury.

Prior to the wide availability of CT, intravenous pyelogram (IVP) was used in patients with suspected renal injury. This was most often in the setting of evidence of either frank or microscopic hematuria. A 1987 study by Oakland and colleagues96 suggested that an IVP should only be performed for naked eye hematuria or prolonged microscopic hematuria. Studies have demonstrated, however, that as many as 20% of significant renal injuries are missed with IVP.95 As CT has become more widely available, the use of IVP has significantly decreased. CT has many advantages over IVP, including providing better injury-specific detail and demonstrating contrast extravasation more reliably as well as injuries to the collecting system with the use of delayed imaging.95 Additionally CT can identify other solid organ and hollow viscous injuries at the same time.

Initial diagnostics for patients with suspected renal injuries include the FAST examination and/or, for those patients deemed stable, CT scan. Patients who have a positive FAST and are hemodynamically unstable should have immediate operative exploration. DPL, which has been traditionally used to identify free intraperitoneal blood, may not be as effective in diagnosing a renal injury because the kidney is located in the retroperitoneum.

It is believed that many patients who undergo exploratory laparotomy for a concerned renal injury simply end up with a nephrectomy as opposed to any attempt for renal salvage.97–99 Because most renal injuries are minor contusions and hematomas, NOM and renal preservation can often be achieved with a minimum of complications.98–102 Additionally, standard routine follow-up imaging is unnecessary for these low-grade (I–III) injuries.103 The management of higher-grade injuries remains, however, somewhat controversial, with varying success rates.102,104 The use of
angiography and embolization has been extended to renal injuries, specifically those with AE on CT scan. Indications for angiography include AE on CT scan and high-grade injury. Angiography has been shown safe in terms of not causing nephropathy due to the contrast agent; however, published success rates vary for the prevention of operative intervention and subsequent nephrectomy.

**Damage Control**

The concept of “damage control laparotomy” originated in the early 1900s to help manage severe liver injuries. The idea is that acute hemorrhage and contamination are surgically controlled; however, definitive repair of injuries is deferred. The idea became popular in the 1980s with the increase in inner-city violence and use of high-velocity, multiple round weapons. For the first time, patients with multiple, severe anatomic injuries were presenting to emergency departments. These constellations of injuries did not seem best managed with a single surgical intervention because it was quickly observed that many of these patients were dying from the physiologic sequelae of their injuries prior to completion of definitive surgical repair. As a result, techniques of abbreviated laparotomy began to be used, with increase rates of survival. In 1993, a landmark article by Rotondo and colleagues coined the term, damage control, and significantly changed the way trauma care is delivered.

It is well known that severely injured trauma patients often die from intraoperative metabolic complications rather than from the inability to repair the injuries. The lethal triad—hypothermia, acidosis, and coagulopathy—once started is difficult and often impossible to reverse in an operating room. As a result, the concept of damage control laparotomy allows for a brief operative intervention, a temporary closure with a vacuum-assisted device, and rapid transfer to an ICU where resuscitation can continue. Once patients have been warmed, coagulopathy treated, and acidosis reversed, they are considered physiologically resuscitated/stable and can better tolerate additional and longer operative interventions for definitive repair. The role of intensivists and the care provided by an ICU is paramount in improving survival and allowing early and safe return to the operating room for definitive surgical management. The specific appropriate timing of this reoperation is unknown; however, according to Rotondo and colleagues, aggressive intensive care management can return normal physiology within 48 hours. The goal of the second operation should be removal of any packing, definitive repair of known injuries, evaluation for missed injuries, and planned closure of intestinal wall and skin. If the abdominal cavity is unable to be closed, once again a temporary vacuum-assisted device is placed and planned reoperation is planned. Unfortunately, each time definitive closure is not achieved, the likelihood of complications, including enterocutaneous fistulae, intra-abdominal sepsis, and resultant long-term hernia, increases.

The ideas and principles of damage control have been expanded beyond the abdomen. Similar techniques have been used for thoracic and vascular trauma. In 2000, Scalea and colleagues applied the principles of damage control surgery to trauma orthopedics and coined the term, damage control orthopedics. Just as Rotondo and colleagues revolutionized the surgical management of the abdomen in critically injured trauma patients, the application of damage control to orthopedic trauma has changed the way care is delivered. Damage control orthopedics has been shown associated with a lesser systemic inflammatory response than early total care fracture fixation.
Abdominal Compartment Syndrome

As its name implies, abdominal compartment syndrome (ACS) consists of a constellation of clinical findings leading to a diagnosis. The term is believed to have been coined in a 1989 publication by Fietsam and colleagues. The investigators described intra-abdominal hypertension from a ruptured aortic aneurysm causing “increased ventilatory pressure, increased central venous pressure and decreased urinary output.” The concept of ACS was first suggested in the late 1800s by several investigators who described that the “effects that respiration produces on the thorax are the inverse of those present in the abdomen,” and, who seem to have been the first to measure intraabdominal pressures (IAPs). In 1874, Wendt was the first to describe an association between elevated intra-abdominal pressure and organ dysfunction.

Today, ACS is defined as a sustained IAP greater than 20 mm Hg that is associated with new onset of organ dysfunction or failure. Today, ACS is defined as a sustained IAP greater than 20 mm Hg that is associated with new onset of organ dysfunction or failure.6,128 IAP is determined by measuring a bladder pressure transmitted through a Foley catheter. It should be measured at end expiration while a patient is supine and relaxed or sedated and the transducer is zeroed at the midaxillary line. Even a slight elevation of the head of the bed can cause an erroneous reading. Clinicians should be cognizant of symptoms of organ dysfunction, which can manifest as oliguria, hypoxia, hypercarbia, increased peak airway pressures, persistent hypotension, or increased acidosis from intestinal ischemia. Risk factors for developing ACS include massive crystalloid fluid resuscitation (>5000 mL in 24 h), massive transfusions (>10 unit PRBC in 24 h), hypothermia, base deficit/acidsis (pH<7.2), and a body mass index greater than 30.6,128,129

ACS has been classified as primary, secondary, or tertiary. Primary ACS refers to a situation when a primary intra-abdominal cause (ruptured aneurysm, abdominal trauma, or retroperitoneal hematoma) is the cause of ACS. Secondary ACS refers to a condition as a result of massive bowel edema secondary to conditions that required massive volume resuscitation, which most commonly occurs after hemorrhagic shock or severe burns. Decompressive laparotomy is the definitive treatment regardless of whether it is primary or secondary ACS. Tertiary or recurrent ACS is rare and usually occurs after a previous episode of ACS has resolved and there is aggressive attempt at abdominal closure in an edematous patient with an open abdomen. Over the past 10 years, the incidence of ACS has decreased, mostly due to adoption of massive transfusion protocols limiting the volume of crystalloid infusion as well as damage control techniques and temporary abdominal closure methods.

SUMMARY

Rapid evaluation, diagnostics, and intervention of injured patients presenting in shock are paramount for good outcome and improved survival. Over the past 30 to 40 years with advances in technology, including bedside ultrasonography and the multidetector CT technology, the techniques for diagnosing hemorrhage and shock have changed. The basic concept of trauma care, however, has remained the same, which is rapidly identifying sources of hemorrhage and shock, delivering adequate resuscitation, and providing definitive care as quickly and as safely as possible. Over the past 10 years, resuscitation using blood products has replaced large-volume crystalloid infusions in many centers. Specific ratio of blood products transfused remains unknown and is currently an area of ongoing research. Additionally, when used, the ideal crystalloid remains unknown. NOM of many injuries has become standard of care. Correctly identifying patients for NOM is key to its success. Despite the increase in NOM, many patients with multiple injuries require immediate operative intervention.
Damage control techniques are often used to quickly treat life-threatening injuries and allow for physiologic normalization prior to definitive repair. As trauma care continues to evolve, newer techniques and management algorithms, including expanding catheter-based therapies for hemorrhage, will emerge.

REFERENCES


