Evaluation and Management of the Trauma Patient for the Interventional Radiologist

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ABSTRACT

Interventional radiologists are adopting an increasingly important role in the evaluation and management of the acutely injured patient. The interventional radiologist may be called upon to provide services while hemorrhage is active, the patient is hemodynamically compromised, and a comprehensive trauma assessment is incomplete. The initial diagnostic and management approach to the trauma patient is optimally organized through the principles of advanced trauma life support. A basic understanding of common injury patterns, immediate lifesaving interventions, and principles of resuscitation is of value to the interventional radiologist in his or her interactions with the trauma team and contribution to patient care.

KEYWORDS: ATLS, trauma management

Objectives: Upon completion of this article, the reader should (1) demonstrate a general approach to the early evaluation and management of the trauma patient, based upon the principles of advanced trauma life support; (2) be able to list the commonly encountered injury patterns and required lifesaving interventions; and (3) explain the resuscitation strategies that impact upon the essential and expanding role of the interventional radiologist in the care of the injured patient today.

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Interventional radiologists play an increasingly important role in the initial stabilization and management of critically injured trauma patients. As minimally invasive techniques for the management of traumatic injury continue to improve, interventional radiologists are often consulted to perform procedures on the acutely injured patient, as a means for immediate stabilization, so that further resuscitation and evaluation may proceed. As a result, it is imperative for interventional radiologist to have a basic understanding of the fundamentals of

advanced trauma life support (ATLS) as well as the other aspects of early trauma management as they are practiced today.

ATLS provides a time-tested, managerial battle plan for the initial evaluation and management of the trauma patient. It emphasizes defined roles for all involved caregivers with a single team leader, positioned to dynamically judge changes in patient status and the flow of all immediate interventions, as well as to organize appropriate diagnostic studies and subsequent patient

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Figure 1 Advanced trauma life support provides individuals who have potentially different training backgrounds and clinical experiences with a familiar basis upon which to jointly care for the critically injured patient. The primary survey is conducted nearly simultaneously by different providers under the guidance of the team leader. Other members of the team are assigned specific tasks including the airway and breathing, assessing circulation, obtaining intravenous access, and obtaining vital signs.

care based on the severity of injuries identified. A progression of diagnostic queries and reactive interventions are designed to not only ascertain injuries, but to rapidly and specifically treat those conditions that pose the greatest immediate threat to vital functions and hemodynamic normality. ATLS thus emphasizes a time-efficient, organized, comprehensive detection and initial control of the patient's total injury burden. This common language of methodology provides individuals who have potentially different training backgrounds and clinical experiences with a familiar basis upon which to jointly care for the critically injured patient (Fig. 1). ATLS is applicable in environments as diverse as a busy urban emergency department or a deployed forward surgical team. By its nature and implicit goals, it seeks to reduce chaos and inefficiency as well as to mitigate any care team member anxiety associated with this inherently stressful situation.

The evaluation and management of the trauma patient, by necessity, begins with the ATLS primary survey: a brief and focused physical diagnostic sequence. During this interval, any major life-threatening injuries are systematically identified, and immediate lifesaving interventions are performed. Adjuncts to the primary survey follow temporally and are described below. The secondary survey represents a brief trauma-related history and complete physical examination.

The ATLS primary survey is often described by the mnemonic ABCDE. *A* refers to the evaluation and management of the airway while maintaining control of a vulnerable cervical spine. *B* depicts the assessment of breathing. *C* relates to evaluation of circulation, with the

Figure 2 During the primary survey, following completion of *A* (evaluation and management of the airway), *B* (assessment of breathing), and *C* (evaluation of circulation), a neurological examination (*D* for disability) is done. After clothing is removed to allow a thorough examination of the torso, the patient is covered to avoid hypothermia (*E* for exposure and environment). A cervical collar is maintained until the *C* spine has been "cleared" of an injury. Note the person at the head of the gurney who continues to monitor the airway and breathing. In the event of a clinical deterioration at any time, the primary survey is reinitiated starting with the airway and breathing.

immediate control of active hemorrhage. *D* describes disability—a rapid neurological status assessment. *E* denotes exposure of the patient with environmental control—a prescription to remove all clothing, turn the patient to expose the posterior torso and any other regions where external stigmata of injury may be evident, as well as to cover the patient with some barrier against heat loss.

In each area of concern, the examination is simplified and rapid. Any immediately life-threatening issue must be addressed expeditiously. Although the components of the primary survey may be assessed almost simultaneously by a coordinated trauma team (Fig. 2), lifesaving interventions are best prioritized with airway considerations preceding those of breathing, circulation, and so on. Moreover, the primary survey should be performed every time there is a decline in patient status, no matter when in the temporal course of patient management.¹ If the trauma patient in the interventional radiology (IR) suite begins to deteriorate, reassessment of the ABC's should be completed expeditiously.

The airway in a neurologically intact patient is not difficult to assess. The injured patient who is alert and able to speak normally is maintaining a patent airway. However, this must be carefully monitored as facial fractures with associated bleeding or edema, emesis, or foreign bodies can eventually compromise airway patency. In acutely injured patients, particularly those sustaining blunt trauma, the cervical spine is unlikely

to be “cleared” with respect to occult injury, and airway management must take into consideration the potential for a bony or ligamentous cervical spine injury.

As a general rule, for patients with severe lower facial or neck trauma, tracheal intubation is required in the presence of the following conditions: severe brain injury, documented or highly suspected thermal inhalation injury, severe pulmonary contusion with hypoxemia or ventilatory insufficiency, high cervical spine injuries, or any injury resulting in pulmonary failure. Furthermore, ongoing large-volume resuscitation can cause a decline in respiratory status due to airway or pulmonary edema that may necessitate emergent airway control.¹

Initial airway management is performed with a jaw thrust maneuver with inline cervical spine immobilization and administration of supplemental oxygen. The commonly taught head tilt, chin lift maneuver is contraindicated unless cervical spine injury has been ruled out. Bag valve mask (e.g., Ambu A/S bag (Copenhagen, Denmark)) ventilation should be performed until a definitive airway can be obtained. The Sellick maneuver involves applying cricoid pressure that subsequently compresses the esophagus. It should be performed whenever an Ambu bag is used to prevent gastric insufflation and aspiration at the time of intubation. Tracheal intubation via the orotracheal route is completed while inline stabilization of the neck is maintained by an assistant. This makes intubation more technically difficult, and the assistance of an experienced provider is recommended. As few patients have been fasting prior to the traumatic incident, rapid sequence intubation, employing cricoid pressure, is the preferred method to prevent the potential aspiration of gastric contents. A suction device should always be readily available when managing the airway to facilitate the expeditious clearing of oral secretions or refluxed gastric contents.

Assessment of breathing begins with evaluation of the patient's thorax and neck. Observe for deviation of the trachea, equal and normal expansion of the chest, abnormal chest wall motion, or the use of accessory respiratory muscles. Listen to the patient's speech for labored effort. Auscultate the chest, listening for the presence of equal bilateral breath sounds. Palpate the chest to determine if there is tenderness, crepitus, or areas of abnormal chest wall movement, including flail segments.

Hemodynamic instability associated with tracheal deviation and loss of breath sounds on the side away from deviation is suggestive of a tension pneumothorax and merits immediate thoracic decompression. Jugular venous distension will also be present if the patient is not severely hypovolemic. Needle decompression of the thorax with a 4.5-cm (2-inch) 14- or 16-gauge catheter, placed in the second intercostal space in the midclavicular line, should be performed as a temporizing measure,

followed by a tube thoracostomy.² A muscular individual will require a longer catheter such as a 10-cm Yueh centesis needle. Tube thoracostomy can be performed immediately instead of needle decompression if the equipment is readily available and the procedure can be performed rapidly. Diminished anterior breath sounds in the supine patient with ipsilateral crepitus, but without hemodynamic compromise, is suggestive of a simple pneumothorax. This will often also require a tube thoracostomy that can be accomplished using an 8- or 10-French drain.

Administration of high concentrations of oxygen via a face mask is a standard component of the treatment of the trauma patient until the full scope of injury is known and resuscitation is complete. In the intubated patient, adequate ventilation should also be assured, generally targeting a $p\text{CO}_2$ in the range of 35 to 40 mm Hg.¹

Circulation is assessed, initially, simply by observing the patient. If he or she is alert and oriented, their central nervous system is receiving adequate perfusion. Observe skin color and feel the temperature of the skin. Is the skin warm and dry, or cool and diaphoretic? Capillary refill, often judged at the thenar eminence or great toe, should be less than 2 seconds. Skin color is often utilized as an indicator of perfusion but may be an unreliable end point for dark-skinned individuals. Palpate the radial pulse. Is it strong and regular, or weak and rapid? As a general guideline, a palpable radial pulse indicates a systolic pressure of at least 80 mm Hg. A femoral pulse indicates a systolic pressure of at least 70 mm Hg. Finally, if only the carotid pulse is palpable, the systolic pressure is ~ 60 mm Hg.¹ These observations give a rapid, albeit approximate, estimate of circulatory adequacy but do not rule out shock. Heart rate and blood pressure are more objective findings; however, “normal” vital signs do not always exclude hypoperfusion.

ATLS classifies four grades of hemorrhage (Table 1).¹ Class I hemorrhage is characteristically associated with up to 15% blood volume loss and is manifested by no change in vital signs or minimal elevation of the heart rate. The pulse usually remains below 100 beats per minute (bpm). Class II hemorrhage is often considered the first level of shock, manifesting as a tachycardia, >100 bpm, and narrowing of the pulse pressure. Tachypnea is also seen in this stage. The systolic blood pressure (SBP) changes minimally up to $\sim 30\%$ blood volume loss. Class III hemorrhage, with 30 to 40% blood loss, is associated with the first significant drop in SBP (<100 mm Hg) and the heart rate generally exceeds 120 bpm. Oliguria, restlessness, and changes in skin perfusion are seen in this stage. Class IV hemorrhage (greater than 40% blood volume loss, often exceeding 2000 mL) manifests more profound hypotension, a heart rate greater than 140 bpm, and lethargy.

If profound shock is determined at this juncture of the primary survey, all other considerations become subordinate, and an immediate search to address the source of blood loss must be conducted. The torso is able to sequester significant volumes of blood, and attention must focus upon potential injuries within the thorax, abdomen, and pelvis. In this scenario, all investigations and interventions should proceed in the trauma resuscitation bay, the operating room, or the IR suite.

Within the thorax, the clinical entities of tension pneumothorax, massive hemothorax, open pneumothorax, and cardiac tamponade must be ruled out or treated immediately. A combination of physical examination and plain anteroposterior (AP) chest radiographs often lead to a diagnosis; however, bedside ultrasonography (i.e., focused assessment with sonography for trauma [FAST] exam) is increasingly finding utility. Tube thoracostomy, pericardiocentesis, or possibly thoracotomy may be indicated to treat or control the etiology of the hypotension.

Long-bone fractures can also cause significant blood loss and, in the thigh in particular, do not achieve tamponade prior to significant blood loss. Reduction of these fractures helps to stem ongoing hemorrhage. A traumatically amputated extremity or deep laceration extending to large blood vessels can result in fatal hemorrhage. However, direct pressure can often control these injuries until more definitive management can be undertaken. Placement of commercially available tourniquets to control major arterial hemorrhage has been validated in recent combat casualty care and is again considered an acceptable practice to initially control hemorrhage.³⁻⁵ Blind placement of hemostats on bleeding vessels should not be undertaken, due to the high risk of iatrogenic nerve injury leading to loss of function in the extremity.

A scalp injury can be the source of a tremendous amount of blood loss. Frequently, a scalp injury is initially covered with a dressing; however, topical application of gauze is usually not adequate to control scalp bleeding. Figure-of-eight suturing, approximation with

skin staples, or the placement of Raney clips (that compress the edge of the scalp) may be required as temporizing measures to control bleeding vessels.

During the evaluation of circulation, the adequacy of vascular access, if previously established in the pre-hospital setting, should be reevaluated, and additional intravenous lines should be obtained as needed. The preferred method of vascular access utilizes large-bore (14- to 16-gauge) intravenous catheters that are ideally placed in the antecubital fossa.¹ Central venous access is time-consuming, requires greater skill in the hypovolemic patient, and is fraught with potential complications.¹ Furthermore, the length and diameter of central lines restrict the volume of resuscitative fluid that can be administered per unit time.¹ Introducer sheath central venous catheters are a notable exception to this rule; however, their short length makes dislodgement more common.¹ Systems for intraosseous infusion as well as venous cutdowns are employed when percutaneous access repeatedly fails. Once large-bore intravenous access has been obtained, intravenous fluid resuscitation should be initiated with a bolus of 1 to 2 L of warm normal saline or lactated Ringer's solution.⁶ Hypertonic saline is controversial, although it may be initially valuable in patients eventually requiring massive transfusion.⁷

It is important that hemostatic interventions (dressings, wound packing, tourniquets, and so on) are reevaluated as assessment and definitive management progresses. Rebleeding can occur with resuscitation, return of normal SBP, and loss of vasospasm. The goals of the circulatory evaluation are to identify shock, limit ongoing hemorrhage, restore intravascular volume, and maintain oxygen delivery to end organs.

Following the assessment of circulation, a disability examination focusing on the neurological status of the patient is initiated. The three components of a Glasgow coma scale (GCS) score are determined: eye opening, verbal capacity, and motor score (Table 2). Normality is indicated by a score of 15. Scores between 13 and 15 indicate a mild traumatic brain injury (TBI). Moderate TBI is represented by scores between 9

Table 1 Classes of Hemorrhage

Parameter	Class I	Class II	Class III	Class IV
Blood loss (mL)	≤750	750–1500	1500–2000	≥2000
Blood loss (percent of total blood volume)	≤15	15–30	30–40	≥40
Pulse	<100	>100	>120	>140
Blood pressure	Normal	Normal	Decreased	Decreased
Pulse pressure	Normal or increased	Decreased	Decreased	Decreased
Capillary refill	Normal	Delayed	Delayed	Delayed
Respirations	14–20	20–30	30–40	>35
Urine output	≥30 mL/h	20–30 mL/h	5–10 mL/h	Minimal
Mental status	Slightly anxious	Mildly anxious	Anxious and confused	Confused and lethargic

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Table 2 Glasgow Coma Scale

	Score
Eye opening	
Spontaneously	4
To verbal stimuli	3
To painful stimuli	2
None	1
Best verbal response	
Oriented and conversant	5
Disoriented and confused	4
Inappropriate words	3
Incomprehensible sounds	2
None	1
Best motor response	
Obeys commands	6
Localizes pain	5
Flexion withdrawal	4
Abnormal flexion (decorticate rigidity)	3
Extension (decerebrate rigidity)	2
None	1

Glasgow coma scale score = (eye-opening score) + (best verbal response score) + (best motor response score). (Reproduced from Advanced Trauma Life Support Student Manual, 8th ed. with permission from the American College of Surgeons.) Interpretation:

- Maximum score: 15—best prognosis.
- Minimum score: 3—worst prognosis.
- Minimal traumatic brain injury (TBI): 13–15.
- Moderate TBI: 9–12.
- Severe TBI: 3–8.
- Scores of 8 or above have a good chance for recovery.
- Persistent scores of 3–5 are potentially fatal, especially if accompanied by fixed pupils or absent oculovestibular responses.

and 13. A comatose patient has a score of 8 and below. This indicates the presence of a severe TBI and the need to secure a definitive airway if not previously done for other indications. The lowest GCS possible is 3. A second component of the neurological survey is the pupillary examination, noting relative size and reactivity. Both the GCS score and eye exam are determined with this aspect of the primary survey and are repeated as needed to follow the neurological status of the patient.

Once the traditional primary survey is complete, a series of adjunctive interventions are initiated. One of these is the FAST. This constitutes an abbreviated sonographic examination of the abdomen, including the subxiphoid region, the left- and right-upper quadrants, and the pelvis. The specific goal of the FAST examination is to rapidly evaluate the torso for evidence of hemorrhage. The FAST exam often begins with an examination of the pericardium to assess for intrapericardial fluid (blood) and early evidence of impending tamponade. The three areas of the abdomen most likely to accumulate intra-abdominal fluid are then evaluated. Sagittal views of Morrison's pouch (hepatorenal fossa) and the splenorenal recess are acquired. The third region is the pelvis, which is examined via a suprapubic transverse view. The sensitivity of this study depends on

operator skill, patient body habitus, and severity of hemorrhage. The FAST exam requires at least 200 mL of intraperitoneal fluid to be present so that it can be visualized by ultrasound. As can be anticipated, the likelihood of a positive FAST is increased in patients with hemodynamic abnormality.¹

Immediately following the primary survey, a supine AP chest X-ray is obtained and evaluated (Fig. 3). Some centers also routinely obtain AP pelvis films and cross-table lateral cervical spine films to screen for injuries within these regions. The utility of obtaining these studies in hemodynamically normal patients, who will undergo a computed tomography (CT) scan to further evaluate for injuries, is under debate.

Once the primary survey has been completed and immediately life-sustaining interventions have been accomplished, the secondary survey should be initiated. If the patient is unstable, the secondary survey should be abbreviated or eliminated altogether. The secondary survey includes a brief history and systematic head-to-toe evaluation of the patient: the trauma-related history and physical examination. The "AMPLE" history is obtained to determine allergies, medications, past medical history, last oral intake, and events surrounding the injury.¹

The entire patient is inspected and palpated in the course of the secondary survey. The head is examined for bony cranial deformities, crepitus, and tenderness as well as scalp lacerations. Pupillary function, first assessed in the *D* part of the primary survey, is again evaluated. Examination for eye injury includes an abbreviated visual acuity examination as well as gross inspection and evaluation of extraocular muscle function. Facial deformity, tenderness, and crepitus may indicate a facial fracture. Similarly, epistaxis, nasal septal deviation, or hematoma may be consistent with a nasal fracture. Cerebrospinal fluid discharge from the ears or nose, tympanic membrane rupture or hematoma, mastoid (Battle sign) and periorbital ecchymoses (raccoon eyes) are consistent with a basilar skull fracture. Dental trauma, tenderness at the temporomandibular joint, and abnormal alignment of bite (malocclusion) may indicate a jaw fracture. The presence of bilateral mandibular fractures requires special attention as it may be associated with airway compromise due to loss of lingual support.

When inspecting the neck, inline cervical spine immobilization is maintained and the cervical spine is examined for tenderness and step-offs that could suggest a significant cervical spine injury. The position of the trachea is again inspected, and the cervical skin is palpated for crepitus. An evaluation for jugular venous distension is repeated, as well as inspection of wounds and hematomas that could indicate an underlying injury.

The chest is again inspected as was done during the primary survey, however, in more detail with respect

Figure 3 Whenever the flow of the resuscitation allows, after the primary survey has been completed, an anteroposterior radiograph of the chest is commonly obtained to evaluate for a widened mediastinum, a simple pneumothorax, a hemothorax, or chest fractures. A tension pneumothorax should be identified on clinical findings of hypotension, neck vein distension, absent breath sounds, and tracheal deviation. A tension pneumothorax must be treated immediately during the primary survey. It should never be diagnosed with a chest radiograph.

to the clavicles, ribs, and shoulders. The abdomen is inspected and palpated. Distension, tenderness, and muscular guarding or rigidity indicate developing peritonitis and may independently indicate the requirement for an exploratory laparotomy. Ecchymoses and abrasions across the abdomen, as would be produced by a high-riding lap belt ("seatbelt sign") with tenderness to deep palpation should heighten suspicion for hollow visceral injury. The pelvis is inspected by palpating and applying gentle pressure to the pubis, followed by simultaneous gentle pressure to both iliac wings, at the anterior superior iliac spines, assessing for pain and abnormal mobility. Pain and instability in the conscious patient suggest a pelvic fracture. These diagnostic maneuvers should not be vigorous or repetitive to avoid iatrogenic hemorrhage.

The urethral meatus is inspected for blood. The genitalia and perineum are inspected for hematomas or ecchymoses. A digital rectal examination evaluates for gross blood, rectal tone, and the position of the prostate. If no blood is found at the urethral meatus and the prostate is not displaced superiorly, a Foley catheter is routinely placed in the severely injured patient. How-

ever, if blood is present at the meatus, a perineal ecchymosis is noted, or a Foley catheter does not pass with ease, a retrograde urethrogram is indicated. This will identify a urethral injury that may preclude blind insertion of a catheter.

If a severe AP (open book) pelvic fracture is suspected on physical examination or identified by plain film, a bedsheet wrap or commercially available pelvic binder should be placed and tightened to reduce pubic diastasis. The binder should be placed at or just above the greater trochanters. This reduces the volume of the pelvis, approximates fractures to prevent displacement and pain, reduces the risk of further vascular injury, and helps to tamponade the pelvic venous plexus. The thoracic, lumbar, and sacral spines are further inspected and palpated. The extremities are similarly examined and ranged to evaluate for injury. Distal pulses are palpated and suspected fractures are splinted.

Once the initial evaluation has been completed, to the level of detail appropriate for the patient's hemodynamic stability, a decision point has been reached. In the stable patient, further ancillary studies are routinely undertaken. Laboratory analyses are routinely obtained

including complete blood count, chemistry panel, coagulation panel, arterial blood gas, liver function tests, urinalysis, and toxicology screening. The advent of point-of-care testing renders the results of some of these laboratories available in time to assist in the acute decision making. If the patient's status allows, further detailed physical examination of injuries, plain radiographs of suspected fractures, and a 12-lead electrocardiogram, in patients with a cardiac history or risk factors, are completed.

A CT scan is an important adjunct to the physical examination and plain radiographs in the assessment and triage of the multiply injured trauma patient. It should be emphasized that movement to the CT suite is reserved for the hemodynamically stable patient, as access to the patient and resources allowing intervention for sudden destabilization are temporarily compromised. An unenhanced CT scan of the head is obtained in patients with significant loss of consciousness, with a GCS <15, or with significant cranial trauma on physical examination. A facial CT scan is employed in a patient with evidence of facial trauma, based upon the secondary survey. A CT scan of the cervical spine is obtained in a patient with cervical spine tenderness to palpation, a depressed mental status, or significant distracting injury. Torso scans, including the chest, abdomen, and pelvis, are obtained to rule out great vessel, pulmonary, solid organ, hollow viscus, and bony injuries as dictated by mechanism and physical signs of trauma. Many busy trauma centers have adopted the routine use of combining multiple CT examinations ("pan-scanning") in an effort to avoid missed injuries.

Most trauma patients who require the care of an interventional radiologist have undergone a primary and secondary survey. Through physical examination and imaging studies, injuries requiring the care of an interventional radiologist may be identified early in this initial evaluation. These include potentially devastating injuries, such as splenic and hepatic lacerations, great vessel disruptions, and pelvic fractures, all of which can lead to profound hemorrhage. These are usually heralded by active intravenous contrast extravasation, aneurysmal dilatation, or vascular dissection on screening CT studies. The interventional radiologist may find him- or herself involved in the management of these patients within minutes of injury identification, even while the trauma patient remains hemodynamically abnormal. Moreover, because of the need for emergent intervention to control hemorrhage, the interventional radiologist is often consulted in the care of critically injured trauma patients while the initial workup is incomplete.

IR services may be called upon to stop hemorrhage in a variety of settings: the IR suite, in the operating room (as an adjunct to an open operative case), as well as, potentially, in the intensive care unit.

Changes in patient status mandate expedient reevaluation, regardless of physical location. This rapid reassessment, initiated with a repetition of the ATLS primary survey, facilitates the identification of missed injuries or the failure of current management strategies to control problems that have already been identified.

The hemodynamically abnormal patient, who does not respond to initial resuscitation, will usually be taken emergently to the operating room to control hemorrhage. These patients will likely undergo exploration of the body cavity or cavities with the highest probability of harboring the site of exsanguination. This assessment is based on clinical suspicion, derived from the mechanism of injury, the superficial injury pattern, the FAST examination, AP chest and pelvis pelvic radiographs, the output of thoracostomy tubes, and, if performed, diagnostic peritoneal lavage. Though these patients may have been taken to the operating room, their ongoing hemorrhage may still require the assistance of the interventional radiologist because of the injury location and issues of inaccessibility.

Liver lacerations and hemorrhage from pelvic fractures are infamously difficult to control even with packing and damage control techniques. The patient who has had an emergent abdominal exploration or thoracotomy may be brought from the operating room directly to the IR suite for angiography and embolization based solely on the findings in the trauma room and in the operating room (Fig. 4). However, if operating room support is adequate in terms of fluoroscopy, angiographic equipment, and technical training and, if patient

Figure 4 Interventional radiologists often perform procedures on the acutely injured patient as a means for immediate stabilization so that further resuscitation and evaluation may proceed. An embolization for hemorrhage from the liver, spleen, or pelvis is a routinely performed procedure in many trauma centers. A trauma embolization can be done either prior to or after a damage control laparotomy that addresses the patient's other life-threatening injuries. Excellent coordination of care between the trauma and interventional radiology services is critical to optimize outcome in the multitrauma patient.

status demands, the interventional radiologist can also perform selective embolization in the operating room. This may be needed in the patient whose total trauma burden remains unknown and frequent reevaluation is requisite. Active resuscitation is usually proceeding for such patients. A hybrid operating room with fixed fluoroscopic equipment would be the ideal setting for a trauma laparotomy, which is complemented by an endovascular intervention. Alternatively, the use of a portable fluoroscopy unit (C-arm) may be the only means to accomplish the endovascular intervention.

The trauma patient who initially presents with hemodynamic instability and responds well to initial volume resuscitation but subsequently manifests recurrent hypotension ("transient responder") is a patient who has persistent bleeding and may benefit significantly from interventional radiologic techniques. This patient is often temporarily stable enough to obtain CT scans that can demonstrate the injuries requiring intervention. The specific injuries are better defined, allowing angiography to be optimally targeted.

The initial resuscitation of the trauma patient is a dynamic area of ongoing research and an area of concern that may coincide with the interventional radiologist's management of active hemorrhage. Blood product utilization is an area of trauma management where a widely accepted algorithm has not yet emerged. Generally, early trauma resuscitation is initiated with readily available crystalloid intravenous fluids: normal saline or lactated Ringer's solution. If shock persists after 2 to 3 L of crystalloid resuscitation in the emergency department, packed red blood cell (PRBC) transfusions are initiated. These are usually not type matched, in the face of time urgency, and are either type specific or, most often, O- or O+ for females and males, respectively. Traditionally, 4 to 6 U PRBC are transfused prior to the initiation of fresh frozen plasma, platelet, and cryoprecipitate units. The optimal end point for intravascular resuscitation is also often obscure. Some have argued that permissive hypotensive resuscitation, with goals of SBP as low as 70 mm Hg, may be sufficient; however, this paradigm has only been applied to penetrating trauma. Generally, the goal of an SBP of at least 90 mm Hg is the goal of intravenous fluid and blood product resuscitation.^{1,8}

In the patient with persistent hemorrhage, with an ongoing transfusion requirement, the appropriate mix of PRBC, plasma, platelets, and cryoprecipitate is unknown. Targeting correction of laboratory values such as partial thromboplastin time, prothrombin time, and international normalized ratio (INR), serum fibrinogen level, and platelet count and function is difficult due to the time delay between obtaining the specimen, processing, and reporting of the laboratory study. Point of care testing such as thromboelastography is not universally available and standardized.

Current literature supports increasing the relative quantity of plasma transfused with respect to each unit of PRBC. Combat casualty care experience, recently gleaned from the Iraq war, demonstrates a higher survival rate in patients transfused with plasma:PRBC ratio of 1:1.4 in distinction from those transfused with ratios of 1:2.5 and 1:8. However, a randomized prospective study has yet to be completed in the civilian trauma population where blunt trauma is the norm.^{9,10}

Despite the absence of consensus regarding hemostatic resuscitation, other traditional clinical targets remain less controversial. These include the directive to transfuse with blood products until massive bleeding has been definitively controlled. Resuscitation goals of mean arterial pressures approximating 65 mm Hg, heart rate <100 bpm, arterial oxygen saturation >94%, central venous pressure of 8 to 12 mm Hg, improved base deficit or lactate to near normal, mixed venous oxygenation saturation >70%, and urine output exceeding 0.5 mL/kg/h are commonly accepted. Goals and corrections for coagulopathy, either demonstrated visually at the time of surgery or by laboratory values, have consensus. Examples include fresh frozen plasma for an INR >1.5, cryoprecipitate to maintain fibrinogen >100, and platelets to maintain the platelet count >50,000 μ L.^{11,12}

Special consideration must be made to the patient's temperature. Hypothermia is associated with worsened patient outcome and is identified as part of the deadly triad along with coagulopathy and acidosis. Once the physical examination of the patient is complete, the patient should be covered with warm sheets and blankets. Optimal care would include warming blankets, warmed intravenous fluids and blood products, as well as heated ventilator circuits. This emphasis on warming is of the utmost importance while the patient is in the operating room where exposure and evaporation contribute to heat loss. Additionally, the IR suite personnel must give special consideration to warming the patient as the IR suite ambient air temperature has an upper limit due to equipment requirements.

In summary, the interventional radiologist currently plays an increasingly important role in the non-operative and postoperative management of the injured patient. Due to improvements in technology and the desirability of minimally invasive treatment of traumatic hemorrhage, the interventional radiologist will find him- or herself more involved in the care of hemodynamically abnormal patients. In such clinical situations, an excellent understanding of the components of the primary assessment, reassessment, basic lifesaving procedures, and resuscitation of these critically ill patients is vital to the interventional radiologist who has become an integral part of the trauma team. If the interventional radiologist has an excellent understanding of how to optimally integrate his or her contributions into this

process, the patient is more likely benefit and to have a successful outcome.

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