Where Does Interventional Radiology Fit in with Trauma Management Algorithm?

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Abstract

Trauma is a major cause of death in the United States, particularly in the younger population. Many traumatic deaths, as well as major morbidity, occur secondary to uncontrolled hemorrhage and eventual exsanguination. Interventional radiology plays a major role in treating these patients, and interventional techniques have evolved to the point where they are an integral part of treatment in these critically ill patients. This article reviews the role of interventional radiology in the treatment algorithms for traumatic injury sponsored by major societies and associations.

Keywords
- trauma
- hemorrhage
- embolization
- algorithm
- interventional radiology

Trauma is the leading cause of death in people aged 45 years and younger, accounting for 10% of deaths globally per year. Exsanguination is the major cause of preventable mortality.[1] In the management of the severely injured and bleeding patient, the cornerstone is represented by early detection and aggressive management of hemorrhage. Uncontrolled hemorrhage results in trauma-induced coagulopathy which is responsible for more than half of the deaths within the first 48 hours after hospital admissions.[2]

Interventional radiology (IR) is part of the nonoperative management (NOM) algorithm for a trauma patient. Conventional role of IR endorsed by most guidelines includes management of patients who are hemodynamically stable. The World Society of Emergency Surgery (WSES) guidelines define hemodynamic instability in an adult patient as admission systolic pressure[3]:

$<$90 mm Hg with clinical evidence of hemorrhagic shock.
$>$90 mm Hg but requiring bolus infusions/transfusions *and/or* vasopressor drugs *and/or* admission base excess greater than -5 mmole/L *or* transfusion requirement of $\geq$ 4 units of packed red blood cells within the first 8 hours.

Increasing availability of equipment and resources is shifting the role of endovascular management in trauma to hemodynamically unstable patients especially in surgically difficult areas like pelvic trauma (PT).[4] According to the American College of Surgeons Committee on Trauma (ACS-COT), the IR team should be available to perform procedure within 30 minutes in level I and level II trauma centers in this low-volume but high-risk patient population.[5] The Society of Interventional Radiology (SIR) position statement for endovascular interventions in trauma requires the IR team to be ready within 60 minutes from the time the decision to proceed with angiography. In addition, SIR recommends that an angiography suite must be available 24/7. In facilities without a 24-hour angiography suite, a protocol should be in place to postpone elective procedures during trauma activation. An algorithm for trauma activation should be created for each trauma scenario in a multidisciplinary approach.[6]

In cases of pediatric trauma, management is more complex due to the specific nature of care. In institutions that are not pediatric trauma centers, pediatric care should adhere to the same algorithm as the adult population. Currently, there is only one evidence-based guideline on management of pediatric trauma, specifically on the management of blunt renal trauma.[6] The development of evidence-based clinical practice guidelines is an area of ongoing research.

Creating an Institutional Trauma Protocol for IR Activation and Response

Several studies have observed that delays in IR response times are linked to poor patient outcomes.[7–9] The common denominator in these studies is the absence of an

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institutional protocol for multidisciplinary collaboration. Multiple studies have demonstrated the value of a multidisciplinary institutional protocol in reducing mortality after PT.[10,11] For instance, Chen et al demonstrated a 10-year experience before and after implementing an institutional protocol involving trauma surgeons, orthopaedic surgeons, interventional radiologists, and intensive care specialists. The annual mortality rate in patients who sustained unstable pelvic fractures with an injury severity score (ISS) $\geq$ 5 decreased from 7.8 to 2.4%.[11] The SIR recommends institutional trauma protocols based on available resources. The ACS-COT requires an interventional radiologist to be available within 30 minutes of notification to perform angiography and embolization. Kim et al prospectively evaluated the effect of a well-defined protocol for improving the IR response time to meet the ASC-COT criteria after IR activation.[5] They defined a clear criteria for IR activation, a closed loop electronic feedback system (Pager) for recording activation and response times. The response time was defined as the presence of the IR team (attending, nurse, technician, and anesthesiologist) in the hospital. Utilizing this protocol, they achieved a median response time of 28.5 minutes. Compliance to the ASC-COT criteria was met in 69% of cases. Compared with the historic cohort, the activation to procedure time dropped from 183 to 72 minutes ($p < 0.001$).

It is very important for interventional radiologists to be involved in the creation and implementation of the institutional protocol in Level I and II trauma centers. It is equally important that the IR team develops an internal operational protocol for meeting the ASC-COT requirement or an internally set guideline based on available resources and avoids delays that impact patient outcomes.

Adult Trauma

Pelvic Trauma

Pelvic trauma is a complex condition with a mortality rate as high as 32 to 56%.[6,12] Patients are usually young with a high overall ISS. Rapid exsanguination in PT can arise from venous (80%) or arterial (20%) source. Disruption of the pelvic rim (pelvic fractures) increases the pelvic volume resulting in limited tamponade contributing to bleeding and hemodynamic compromise. Principle veins involved are the presacral and prevesical veins. Arterial bleeds are less common and are more frequently associated with hemodynamic instability.[12] Principle arterial sources are the anterior branch of the internal iliac—the pudendal, obturator, and the posterior branches—superior gluteal, and the lateral sacral.

Standardized workup and management protocols in PT are essential to avoid delays. Evaluation of coagulopathy with thromboelastography or rotational thromboelastometry and volume loss with serum lactate and blood gas analysis are performed for all PTs. Chest X-ray and extended focused assessment for sonographic evaluation of the trauma patients are deployed immediately for all unstable patients. CT is the gold standard and recommended in hemodynamically stable patients. CT has a 98% sensitivity for identifying contrast extravasation. In the absence of extravasation, a hematoma of $\geq$ 500 mL indicates the presence of an arterial injury.[13,14] The application of noninvasive external pelvic compression is recommended as an early strategy to stabilize the pelvic ring and decrease the pelvic volume and thereby the amount of pelvic hemorrhage. Complications include skin ulceration/necrosis due to over tightening or rapid removal of the binder which is not recommended for more than 24 to 48 hours. Resuscitative endovascular balloon occlusion of the aorta (REBOA) has emerged as an alternative to emergent procedural intervention in hemodynamically compromised patients suspected to have pelvic bleeding. REBOA involves the placement of an endovascular balloon in the aorta to occlude the aorta and control the bleeding. The three REBOA zones for positioning the balloon include Zone I (supraceliac), Zone II (pararenal), and Zone III (infrarenal). For most pelvic bleeding, Zone III is preferred. The advantage of this procedure is that it can be performed in the field or in the emergency room. Limitations of the procedure include access to functional femoral arteries and the procedure only temporarily stops the bleeding. Complication includes ischemia–reperfusion organ injury followed by multiple-organ failure. REBOA represents a bridge to intervention technique (surgery/angiography or hybrid procedures).

Another technique to temporize and reduce bleeding complication includes preperitoneal packing (PPP). PPP can be performed in the emergency room. Through a suprapubic midline incision, three laparotomy pads can be placed on each side of the urinary bladder in the retroperitoneal space below the pelvic brim toward the iliac vessels. PPP is effective in controlling bleeding from a venous source which accounts for more than 80 to 90% of the bleeding source in PT. PPP is a complimentary procedure to angioembolization, as the latter is effective in arterial bleeding. Both these techniques represent different mechanisms of stopping pelvic bleeding.

Angioembolization has been shown to be an effective measure in controlling bleeding in hemodynamically unstable patients with an arterial source of bleeding.[6] It is important to understand that pelvic angiography and embolization are expected to benefit only a small proportion of patients and should be employed once extrapelvic and nonarterial sources of bleeding are controlled.

Angioembolization in PT is indicated in the following scenarios (►**Fig. 1**)[12,13]:

1. Pelvic fractures with hemodynamic instability or signs of ongoing bleeding after nonpelvic sources of bleeding have been excluded and efforts for reducing venous bleeding have been performed such as PPP.
2. Arterial contrast extravasation and the presence of a pelvic hematoma on a CT scan regardless of hemodynamic status.
3. Pelvic fractures in those who have undergone pelvic angiography with or without embolization, who have signs of continued ongoing bleeding after nonpelvic sources have been excluded.
4. Patients older than 60 years with major pelvic fractures regardless of hemodynamic status.

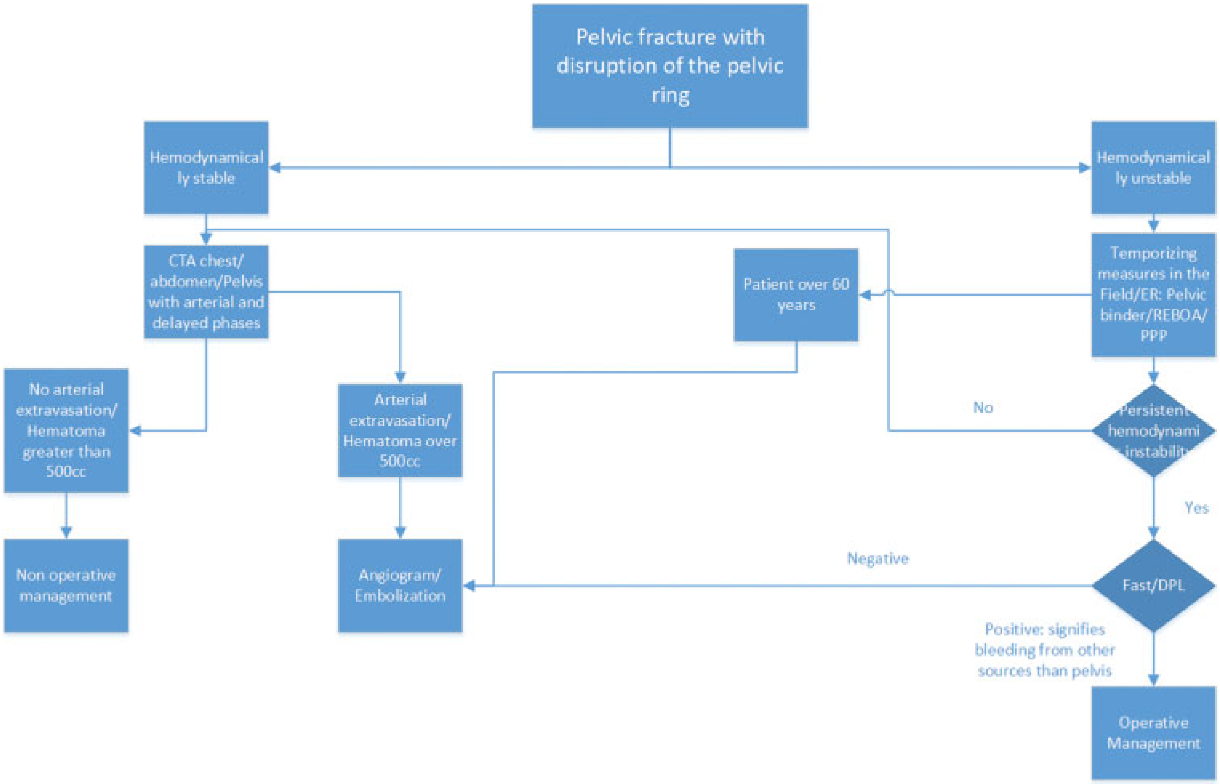

Fig. 1 Algorithm for Management of Pelvic Trauma. CTA, computed tomographic angiography; ER, emergency room; REBOA, resuscitative endovascular balloon occlusion of the aorta; PPP, preperitoneal pelvic packing; FAST, focused assessment with sonography in trauma; DPL, deep peritoneal lavage.

Liver Trauma

Liver is the most commonly injured organ in abdominal trauma. Road traffic accidents are the most common cause of liver injury with blunt trauma occurring at a rate of 71.1% and penetrating injury such as stab and gunshot wounds occurring at a rate of 28.9%.[15] The most common location of liver injury is within the left lobe along the falciform ligament. Surgical operative management (OM) has been replaced by NOM in majority of patients with traumatic liver injury due to the lower complication rates and better outcomes. NOM has been reported to be successful in 50 to 85% of patients with liver trauma.[3] The absolute requirements of NOM are hemodynamic stability and absence of other lesions requiring surgery like hollow viscus injury. The American Association for Surgery and Trauma (AAST) classifies the severity of liver injury into six levels (►**Table 1**). In a stable patient, the gold standard imaging modality is a CT scan with a specificity and sensitivity of 96 and 90.5%, respectively. Delayed-phase CT helps differentiate active arterial extravasation from contained vascular injuries.

Angioembolization is part of the NOM option for hemodynamically stable patients with evidence of ongoing bleeding with an identified extravasation on CT angiography irrespective of the AAST classification. A meta-analysis looking at the success rate of embolization in hepatic trauma patients reported a 93% technical success rate.[6] Complications of angioembolization include hepatic necrosis (15%), abscess formation (7.5%), and bile leak 15.2%.[16] The organ salvage rate after arterial embolization ranges from 86 to 100%.[17] Embolization is also considered in patients who are hemodynamically unstable and continue to bleed despite operative intervention.[6]

Angioembolization in liver trauma is indicated in the following scenarios:

1. Hemodynamically unstable/transient response after OM.
2. Arterial contrast extravasation on a CT scan in a hemodynamically stable patient.

Splenic Trauma

Treatment decision in splenic trauma is based on hemodynamic status. NOM is preferred in patients who are hemodynamically stable without any hollow visceral injury. CT scan is performed in all stable patients. The AAST scores blunt splenic trauma based on CT findings (►**Table 2**). The injury type (laceration, hematoma, vascular), appearance (capsular, subcapsular, intraparenchymal), and size of the abnormality determine the AAST score (►**Table 2**). For AAST I, II, and III injuries who are hemodynamically stable, the mainstay in management is observation unless there is arterial extravasation/pseudoaneurysm present on the CT. Angioembolization is recommended for the latter and/or in patients who have a AAST IV/V but hemodynamically stable. A recent meta-analysis by Requarth et al showed NOM with angioembolization had an overall failure rate of 15%.[18] In higher grade IV and V traumas, the failure rate decreases with the addition of angioembolization therapy.[19] Complications are rare with an incidence of 0 to 7.5% and include secondary hemorrhage, pseudoaneurysm, and

Table 1 American Association for Surgery and Trauma Liver Injury grading system

Grade	Injury type	Injury description
I	Hematoma Laceration	Subcapsular <10% surface Capsular tear <1 cm parenchymal depth
II	Hematoma Laceration	Subcapsular 10–50% surface area, intraparenchymal <10 cm diameter 1–3 cm parenchymal depth, < 10 cm length
III	Hematoma Laceration	Subcapsular >50%, surface area or expanding, ruptured subcapsular or parenchymal. Intra-parenchymal >10 cm diameter >3 cm parenchymal depth
IV	Laceration	Parenchymal disruption involving 25–50% of hepatic lobe
V	Laceration Vascular	Parenchymal disruption involving >75% of hepatic lobe Juxtavenous hepatic injures, retrohepatic vena cava/central major hepatic veins
VI	Vascular	Hepatic avulsion

Table 2 American Association for Surgery and Trauma Splenic Injury grading system

Grade	Injury type	Injury description
I	Hematoma Laceration	Subcapsular <10% surface Capsular tear <1 cm parenchymal depth
II	Hematoma Laceration	Subcapsular 10–50% surface area, intraparenchymal <5 cm diameter 1–3 cm parenchymal depth not involving a parenchymal vessel
III	Hematoma Laceration	Subcapsular >50%, surface area or expanding, ruptured subcapsular or parenchymal. Intraparenchymal >5 cm diameter >3 cm parenchymal depth or involving trabecular vessels
IV	Laceration	Laceration of the segmental or hilar vessels producing major devascularization (25% of spleen)
V	Laceration Vascular	Completely shatters spleen Hilar vascular injury which devascularized spleen

splenic abscesses.[20] Although NOM is the current choice of treatment, OM is needed when NOM fails, or if the patient is hemodynamically unstable. Even with OM, splenectomy is not always performed as the spleen has a key role in immunologic function. Studies of NOM have shown that the immune function after splenic artery embolization remains intact.[6]

Angioembolization in splenic trauma is indicated in the following scenarios:

1. Arterial contrast extravasation, pseudoaneurysm, arteriovenous on a CT scan in a hemodynamically stable patient irrespective of AAST classification.
2. Hemodynamically stable, AAST grades IV and V regardless of the presence of extravasation on CT.
3. Hemodynamically stable with persistent hemorrhage regardless of the CT finding once extrasplenic sources of bleeding have been excluded.

Kidney Trauma

Renal injury accounts for 1 to 5% of traumatic injuries[21] and is classified into five grades by the AAST (►**Table 3**). The most common causes for injury are contusions and superficial laceration (AAST I, II), which are often self-limited. Major grade V injuries are rare and require surgical intervention, usually a nephrectomy. AAST grades III and IV are most likely to benefit from angioembolization. Conservative NOM is currently used in approximately 80% of high-grade renal injuries.[21] Surgical intervention is preferred in cases of hemodynamic instability, multiorgan involvement, urine leaks, or more than 50% of kidney involvement.[6]

Angioembolization in renal trauma is indicated in the following scenarios:

1. Arterial contrast extravasation, pseudoaneurysm, and arteriovenous fistula on a CT scan in a hemodynamically stable patient.
2. AAST grades III and VI when surgical exploration is not warranted.

Aortic Trauma

Aortic injury is a life-threating condition that occurs most commonly after sudden deceleration as in motor vehicle accidents and fall from a height. The incidence of traumatic aortic injury (TAI) is low occurring in 0.3 to 1% of all trauma, but only 20% of patients survive to reach the hospital.[22,23] Majority of the TAI occurs in the proximal descending aorta. In the past decade, thoracic endovascular repair (TEVAR) has become the mainstay in the treatment of TAI. TEVAR is associated with increased survival and decreased neurological deficit and spinal cord injury compared with open repair and NOM.[24] Society of Vascular Surgery classifies TAI into four grades based on the severity of injury (►**Table 4**).[25] Emergent TEVAR is recommended in anatomically favorable grade III and IV aortic injuries, while NOM is recommended for grade I and II injuries.

Table 3 American Association for Surgery and Trauma Kidney Injury grading system

Grade	Injury type	Injury description
I	Hematoma Contusion	Subcapsular, nonexpanding without parenchymal laceration Microscopic or gross hematuria. Urological studies are normal
II	Hematoma Laceration	Nonexpanding perirenal hematoma confined to the renal retroperitoneum <1.0 cm parenchymal depth of the renal cortex with no urinary extravasation
III	Laceration	>1.0 cm parenchymal depth of renal cortex w/out collecting system rupture or urinary extravasation
IV	Laceration Vascular	Parenchymal laceration extending through the renal cortex, medulla, and collecting system Main renal artery or vein injury with contained hemorrhage
V	Laceration Vascular	Completely shattered kidney Avulsion of the renal hilum that devascularizes kidney

Table 4 Society of Vascular Surgery Aortic Injury grading system

Grade	Aortic injury
I	Intimal tear
II	Intramural hematoma
III	Pseudoaneurysm
IV	Rupture

Extremity Trauma

Peripheral vascular injury (PVI) affecting the extremity accounts for 45 to 80% of all vascular traumas. In general, lower extremities are more often injured than upper extremities. PVIs are graded according to the AAST organ injury scale (►**Table 5**).[26] Most patients with significant PVI will need operative intervention to fix conditions other than the vascular injury. Two anatomical locations where endovascular interventions have emerged are for iliac and axillary–subclavian arteries. In both these locations, endovascular repair with stent placement has shown to reduce complication rates compared with open repair.[27] Embolization to stop hemorrhage in arterial injury should be considered in areas where the embolization would not lead to limb loss.

Table 5 American Association for Surgery and Trauma Extremity Vascular Injury grading system

Grade	
I	Digital artery/vein, palmar artery/vein, deep palmar artery/vein, dorsalis pedis/plantar artery/vein, non-named arterial and venous branches
II	Basilic/Cephalic vein, saphenous vein, radial artery, ulnar artery
III	Axillary vein, superficial/deep femoral vein, popliteal vein, brachial artery, anterior tibial artery, posterior tibial artery, peroneal artery, tibioperoneal trunk
IV	Superficial and deep femoral artery, popliteal artery
V	Axillary artery, common femoral artery

Pediatric Trauma

Abdominal Trauma

Abdominal trauma is present in approximately 25% of pediatric trauma patients.[28] Pediatric trauma is usually blunt in nature (90%), with the spleen being the most commonly involved organ.[29] Splenic trauma is especially of concern due to the immunological properties of the spleen, which is particularly important during childhood. Ten percent of all pediatric blunt abdominal trauma involves injury to the kidney.[30]

Abdominal trauma can be characterized by grade of injury based on the 2000 American Pediatric Surgery Association (APSA) guidelines. Management of the patients is based on hemodynamic status rather than grade, as it is safe and more cost-effective.[31] Diagnosis includes clinical parameters like age-adjusted shock index, imaging findings on focused abdominal sonography in trauma, contrast-enhanced ultrasound using a second-generation intravenous contrast agent, and CT.[31] Based on hemodynamic stability, initial management includes fluid boluses of normal saline or Ringer's lactate and transfusion with packed red blood cells. The standard management of solid-organ injury in pediatric patients is nonoperative. More than 96% of injuries may be managed without surgery.[31] NOM failure occurs early within the first 48 hours. Reasons for failure include shock, continued hemorrhage (49%), peritonitis (42%), pancreatic injury (8%), and ruptured diaphragm (1%).[31] Angioembolization can be used to control bleeding, even though a majority of children with contrast extravasation do not require it. The role of angioembolization is limited to children who are experiencing NOM failure.

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