Doi 10.26269/eyg2-vs37

Current opportunities of emergency and urgent interventional care in vascular posttraumatic damage

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Abstract
Trauma is one of the leading causes of mortality. There is a need for effective and efficient delivery of care that can improve survival and reduce morbidity as much as possible. Since the development of angiography and transcatheter techniques, interventional radiology has played an important role in the management of trauma patients. The ability to treat life-threatening hemorrhage with transcatheter embolization has spared countless patients the morbidity of surgery. As the applications of transcatheter therapy broaden to include embolization of unstable patients with solid organ injuries and endovascular repair of major arterial injuries, the interventional radiologist must be increasingly prepared to provide prompt, efficient, and high-quality service.
Key words: trauma, interventional radiology, transcatheter embolization, stent-graft.

Trauma is the third overall leading cause of mortality across all ages. It remains the leading cause of death among 1 to 44 years old causing 193,000 deaths annually in USA. The first description of the use of transcatheter embolization of the internal iliac artery to control hemorrhage associated with pelvic fractures was published in 1972.1 Since that time, the role of interventional radiologists in trauma has evolved from that of making the initial diagnosis of vascular and solid organ injuries to temporizing or definitive treatment. Interventional radiologists are ideally qualified to play an important role in the management of trauma patients. With recent advances in endovascular techniques, there is an increasing role for it in the management of traumatic hemorrhage. Equally important, treatment of trauma patients requires efficient use of resources as well as cooperation and communication among a multidisciplinary team. Patients need to be rapidly and accurately assessed to determine the nature of their injuries with treatments prioritized by injury severity. Angiography provides quick imaging, accurate diagnosis, early procedural triaging, and potentially shortens the time from diagnosis to intervention.

CATHETER ANGIOGRAPHY

Indications for emergency catheter angiography in the trauma patient include clinical signs or symptoms of hemorrhage or CT evidence of ongoing hemorrhage or vascular injury. In the selected trauma patient with suspected vascular injury or hemorrhage, diagnostic catheter angiography usually is performed. Catheter angiography may be performed as a screening procedure or to plan definitive transcatheter or surgical therapy. It is used as follows:

- A large-field nonselective study, such as an abdominal aortogram, is obtained first. Angiography may detect bleeding and may help in planning further selective studies;
- Selective studies are performed to detect more subtle hemorrhage and vascular injuries and to direct further treatment;
- Angiography should be performed as quickly as possible for the immediate diagnosis of bleeding and subsequent embolization or stenting of the area of vascular damage.

INTERVENTIONAL TREATMENT MODALITIES

The following interventional treatment methods are commonly utilized in the trauma setting:

- **BALLOON OCCLUSION:** Inflation of an angioplasty balloon proximal to a major arterial injury may temporarily stop or reduce life-threatening hemorrhage and thereby stabilize the patient while definitive surgical or endovascular repair is being arranged;
- **TRANSCATHETER EMBOLIZATION:** Embolization is an intentional occlusion of a vessel to arrest blood flow by deposition of embolic materials directly into the vessel via an angiographic catheter. Transcatheter embolization can stop arterial hemorrhage, thus improving unstable hemodynamics and often avoiding the need for surgery. The primary goal of embolization is to control the hemorrhage at its source intravascularly. The secondary goal is to prevent embolic material traveling to non-targeted organ tissue, thereby preventing organ dysfunction and associated sequelae. Prompt, effective, and safe transcatheter embolization requires skill and knowledge of the available equipment, arterial anatomy, role of collateral arterial flow, and risks. A variety of catheters, including coaxial microcatheters, are available for selective catheterization to virtually all parts of the arterial cir-

culation. Embolic agents vary in their permanency and the anticipated level of arterial occlusion. The choice of embolic agent will vary based on the site and nature of the injury, the desire to preserve collateral flow, and operator preference. Gelfoam, microparticles and coils are some of the most commonly selected embolic agents in trauma. Transcatheter embolization of active hemorrhage or vascular injury often is considered preferable to surgical treatment. Transcatheter embolization is the mainstay of modern interventional trauma radiology.

- **STENTS:** Stent-grafts or covered stents provide a means of salvaging injured or hemorrhaging arteries and increase the options for transcatheter treatment. Stent-grafts are increasingly being applied to the treatment of large vessel injuries and may enable one to avoid complex surgical vascular repairs in areas with trauma-related anatomic distortion and in patients who may be unstable. Stent grafts have been used successfully in the treatment of arterial rupture or pseudoaneurysm in suitable vessels. Bare stents have been used successfully in the treatment of intimal dissection.

SOLID VISCERAL INJURIES

The spleen is the most commonly injured solid abdominal organ, closely followed by the liver, with injuries occurring as the result of blunt or penetrating trauma. Less frequently the kidney, mesentery, adrenal gland, small bowel, or pancreas is injured.2 In the past, surgery was the only treatment for control of hemorrhage. However, transcatheter embolization quickly earned a role in the nonoperative management of these injuries, particularly where organ preservation was important (Fig. 1).

Imaging plays a large role in the evaluation of trauma patients. Computed tomography (CT) is the best imaging study for evaluation of stable trauma patients. Its sensitivity for injury approaches 100%. Arterial extravasation is identified as a focus or area of high contrast attenuation that does not conform to a normal vascular structure, surrounded by the high-attenuation fluid of a hematoma or is situated within an injured solid organ. This extravasation may be contained, as in the case of a pseudoaneurysm, or uncontained with free spill into the peritoneum. CT-angiography can also be used to evaluate large-vessel integrity with diagnosis of arterial occlusions, transections, dissections, intimal tears, and more.

SPLEEN

Patients with hemodynamic instability and evidence of splenic trauma typically undergo immediate surgery. Hemodynamically stable patients with splenic injury are triaged to nonoperative management with observation or transcatheter embolization. The decision as to who should undergo angiography has changed over time. Early reports advocated mandatory angiography for all patients with imaging evidence of splenic injury who did not undergo immediate surgery.3,4 Unfortunately, many patients did not prove to have arterial injuries at angiography and did not require transcatheter embolization. Subsequently, clinical and imaging parameters were successfully used to stratify patients into those who required angiography and those who could be observed. This division avoided angiography in a majority (74%) of patients.5 CT is the imaging modality of choice to make the diagnosis of splenic injury, and it may help in grading the degree of injury. Currently, the accepted indication for angiography is the presence of active extravasation or pseudoaneurysm formation at CT.6,7 This ''contrast blush'' is strongly correlated with failure of observa-

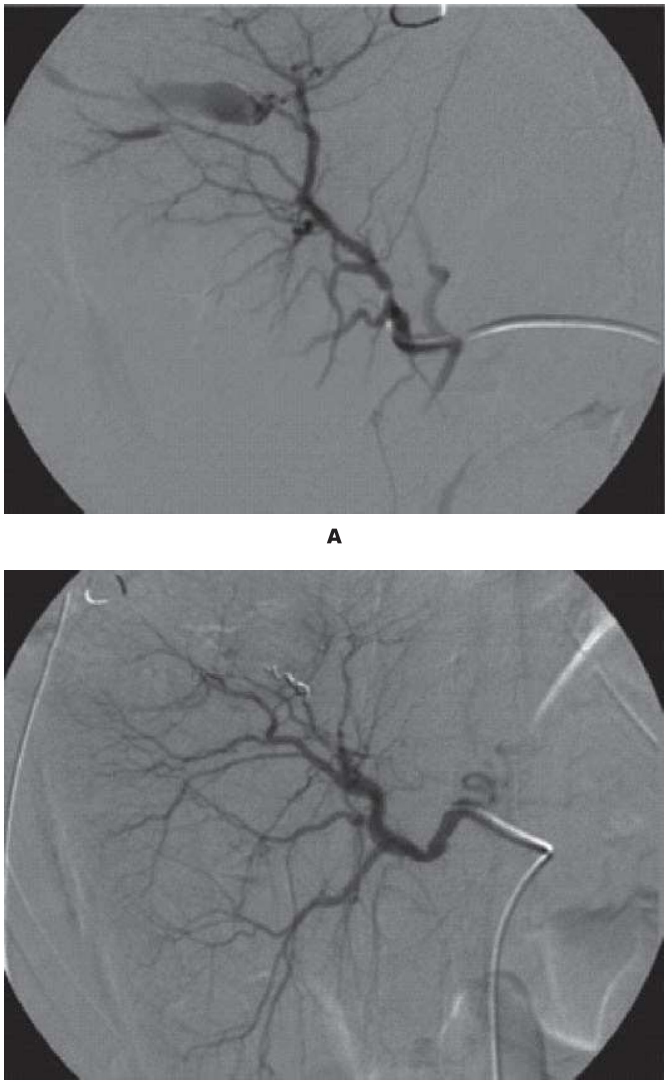

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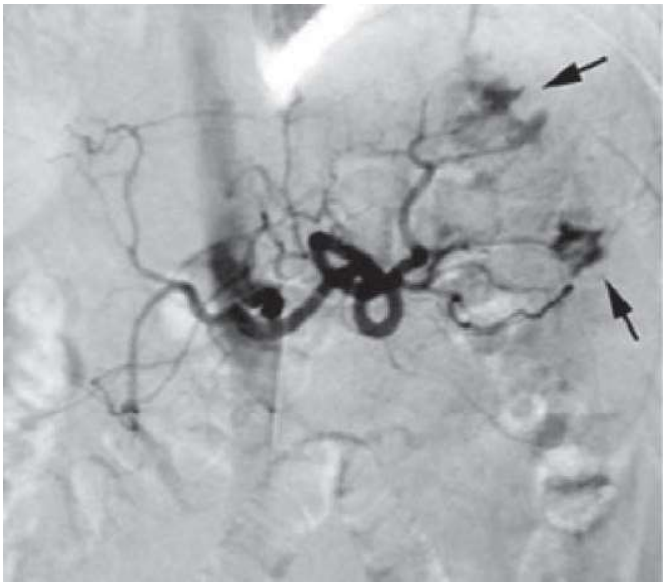
Figure 1. Angiography confirms the extravasation in the right hepatic lobe (A), which was successfully treated with transcatheter embolization using coils super selectively deployed in the bleeding vessel with preservation of surrounding branches (B)



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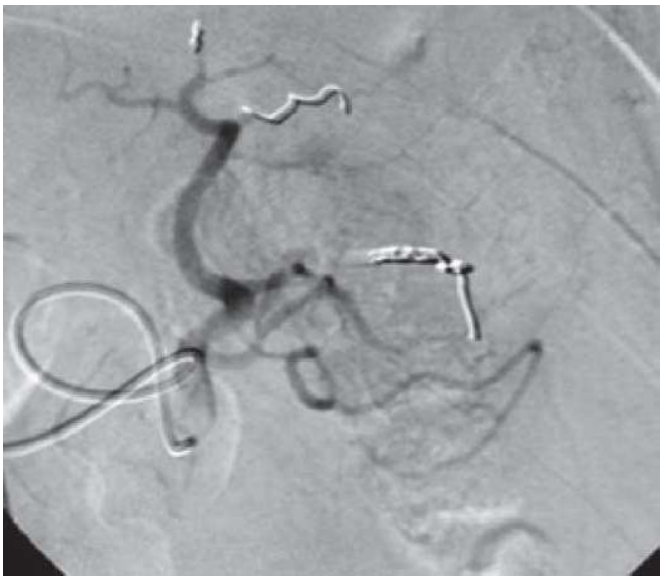


B

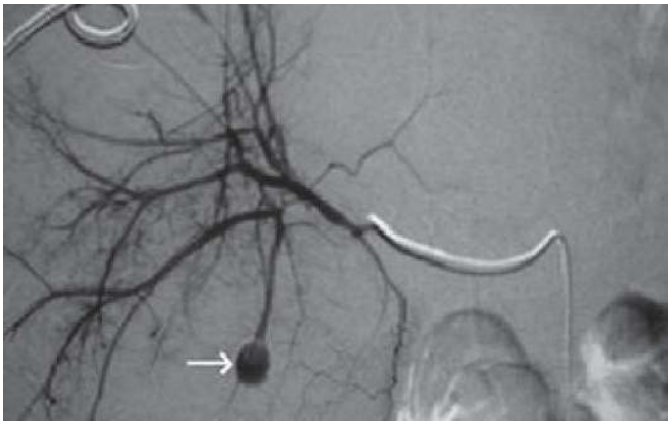
Figure 2. Celiac angiogram showing 3 foci of extravasation in spleen (A), after super selective embolization splenic angiogram demonstrating microcoils in good position and no evidence of further extravasation (B).

tion as nonoperative management.8,9 Stable patients with splenic injuries that do not demonstrate one of these findings can be observed. Most will recover uneventfully, though some will experience delayed hemorrhage requiring intervention.

Two methods are available for splenic transcatheter embolization, proximal and distal embolization, both with proven success. Proximal coil embolization just distal to the dorsal pancreatic artery and proximal to the pancreatic magna artery to reduces pulse pressure to the spleen, promoting native hemostasis, but preserves flow to the spleen through collaterals. Coils should be just larger than the vessel diameter to avoid distal embolization or protrusion into the celiac artery. Distal embolization is typically performed using gelfoam or microparticles distributed by flow. A variant of this is super selective embolization of a single injured vessel, which can be performed using a microcatheter with particles or coils but requires increased time and skill (Fig. 2). Combinations of proximal and distal transcatheter embolization may be useful in some cases. Not surprisingly, postprocedural CT has demonstrated a higher rate and larger size of splenic infarcts following distal embolization as compared with proximal embolization.10,11,12 Thus, proximal transcatheter embolization is recommended for organ preservation with distal transcatheter embolization reserved for refractory hemodynamic instability or control of extra parenchymal extravasation.

LIVER

Hepatic trauma can result in injuries to the hepatic arteries, portal veins or hepatic veins. The mortality rate of surgery for blunt hepatic trauma has been reported to be 33% or greater.13 Therefore, nonoperative management is the treatment of choice for stable patients and may increasingly be selected for some unstable patients as well. CT has proven useful in the



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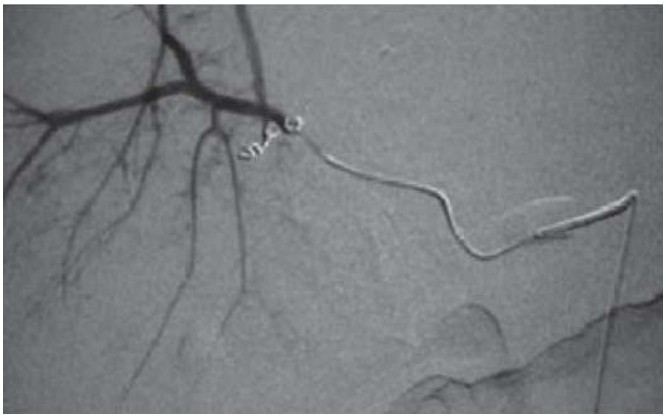

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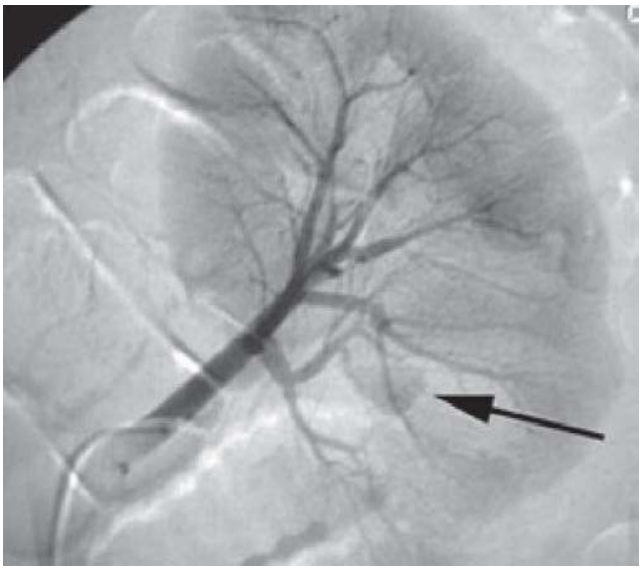
Figure 3. Embolization of traumatic pseudoaneurysm of the hepatic artery (arrow) (A), after selective embolization hepatic angiogram demonstrating microcoils in good position and completely occluding pseudoaneurysm of the hepatic artery (B).

identification of patients who require angiography.14 An estimated 50 to 80% of patients with blunt hepatic trauma should be able to undergo nonoperative management with avoidance of surgery in 98.5%.15 The dual blood supply of the liver makes infarction from transcatheter embolization unlikely provided the portal vein is patent and flow is antegrade, findings that can be confirmed at angiography. In some cases, super selective catheterization and embolization can be performed to preserve uninjured tissue (Fig. 3). Less selective embolization of an entire hepatic lobe or segment may be performed using gelfoam or micro-embollic particles. This method is preferred to treat multiple sites of injury simultaneously and when prompt cessation of hemorrhage is necessary and super selective catheterization is too time-consuming.

KIDNEY

A recent series of consensus documents on genitourinary trauma highlights the evaluation and management of renal injuries.16 Similar to hepatic and splenic trauma, the indications for angiography have varied with time but have a basis in CT imaging. Generally, patients with severe injuries or instability are taken to surgery, but one recent report advocated mandatory angiography of high-grade injuries whenever the clinical condition allowed it, even in the setting of hypotension.17 Embolization should be performed as selectively as possible to preserve uninjured renal parenchyma. Super selective embolization preserves renal function, sometimes better than surgery.18 Both gelfoam and coils are appropriate, though gelfoam may allow for recanalization and tissue preservation. With increasing experience, the role of interventional treatment may expand to include stent-graft insertion for repair of large vessel injury. Transcatheter embolization of injuries to the branch arteries is successful in 84-100% of patients (Fig. 4).18



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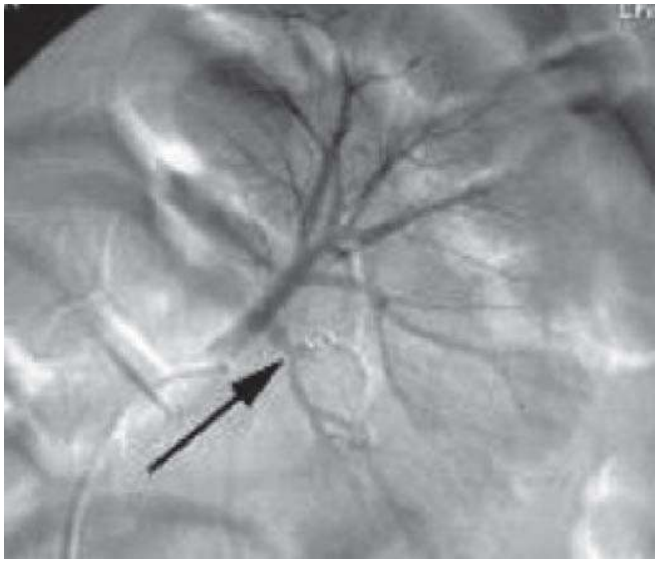

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Figure 4. Left renal angiogram demonstrate a pseudoaneurysm (arrow) of an intrarenal artery branch (A), left renal angiogram shows coil embolization (arrow) completely occluding the renal artery branch previously containing the pseudoaneurysm (B).

AORTA

The aortic injury most concerning in blunt trauma is acute aortic transection, or acute traumatic aortic injury, due to its high mortality. Most patients die before transport to the hospital. Of those who reach the hospital, the overall survival rate is 70% with higher mortality associated with delays in treatment.19 Additional injuries of the aorta and its branches may occur from trauma as well, including intimal tears and dissections. Therapy is generally guided by the nature of the injury and the presence or risk of organ compromise. A high degree of suspicion is needed to diagnose acute traumatic aortic injury. Contrast-enhanced CT has proven utility in evaluation of patients with abnormal chest radiographs and patients for whom there is a high clinical suspicion. 20,21 A normal CT has a negative predictive value of 100% for acute traumatic aortic injury.22 In the past, all patients with abnormal chest CT exams underwent catheter angiography. Catheter angiography has generally been considered the gold standard for diagnosis of acute traumatic aortic injury, but CT-angiography has shown sensitivity, specificity, and accuracy similar to catheter angiography and is supplanting this procedure in many medical centers.19,22 Acute traumatic aortic injury is associated with rapid deceleration in motor vehicle collisions, falls from a height, and crush injuries.19 Most injuries involve partial or full-thickness disruptions of the aortic wall. In patients who reach the hospital alive, 90% occur at the aortic isthmus, with smaller proportions in the ascending aorta just above the aortic valve (8%)

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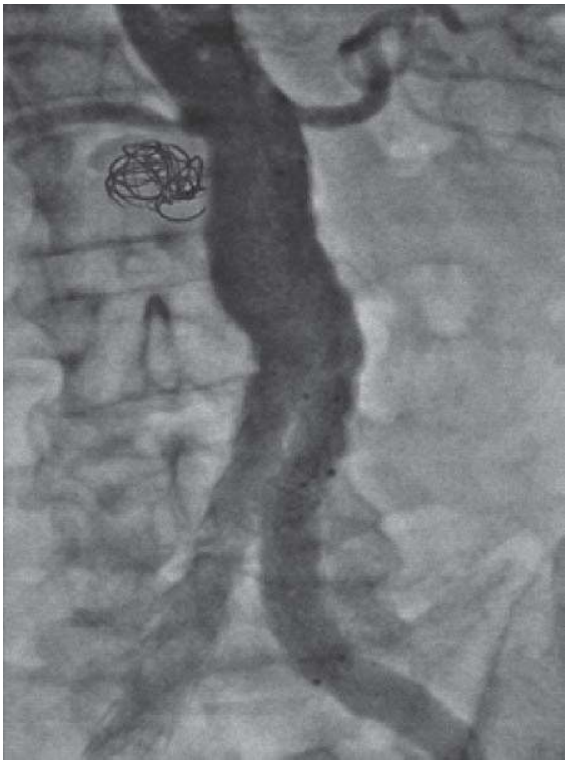

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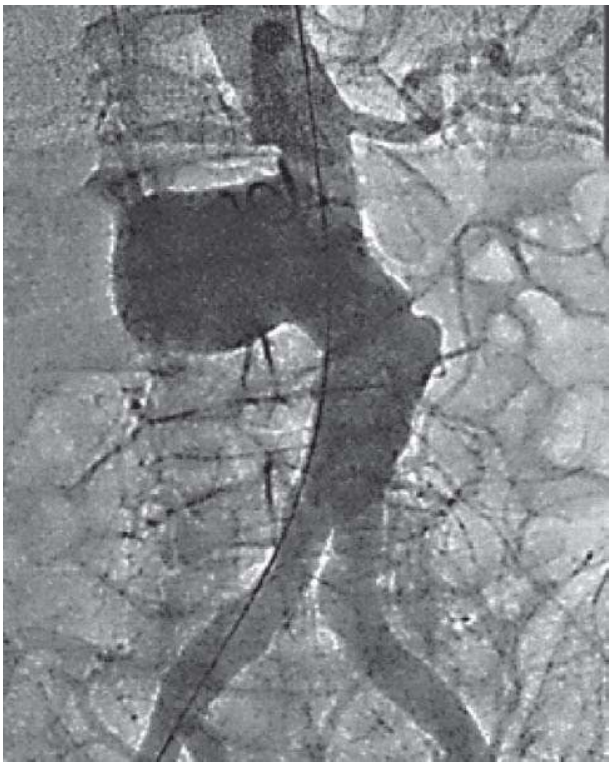
Figure 5. Posttraumatic pseudoaneurysm sac in stent grafted abdominal aorta (A), treated with transcatheter coil embolization (B).



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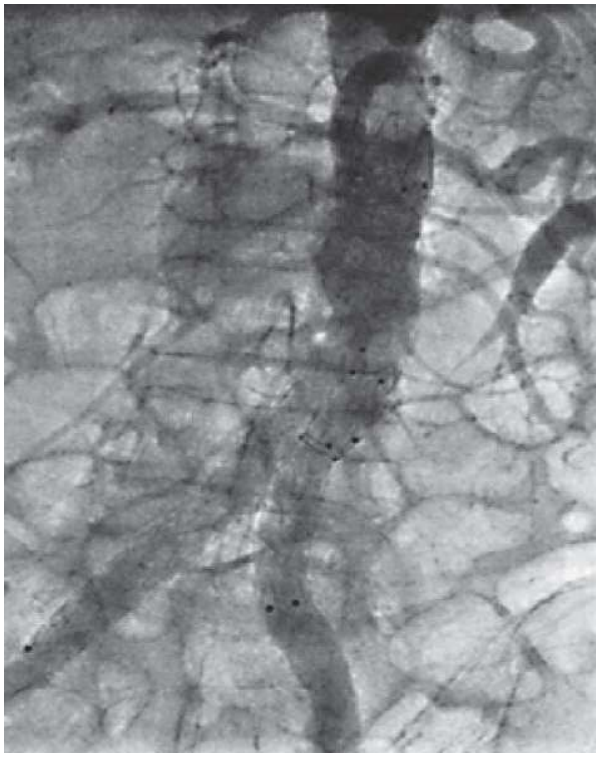

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Figure 6. Posttraumatic infrarenal aneurysm of abdominal aorta (A), treated with endoprosthesis aortic aneurysm using a stent graft (B).

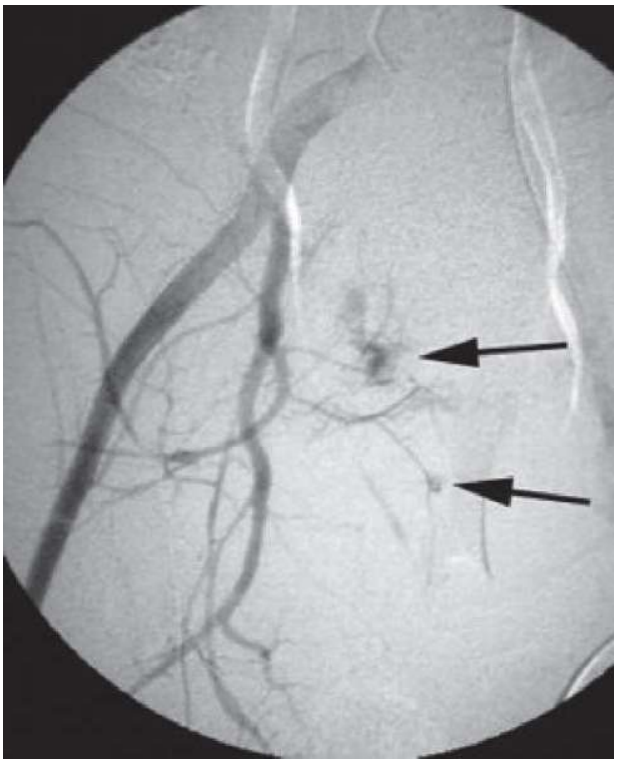
and in the descending aorta at the diaphragmatic hiatus (2%).[22]

Arteriography should include at least two different views of the aortic arch - typically a 45° left anterior oblique and an anteroposterior view. Additional views including right anterior oblique and lateral projections can be obtained as needed. Arteriographic findings include an abnormality or outpouching of the aortic contour, an intimal flap or dissection, retention of contrast in a pseudoaneurysm sac (Fig. 5). The proxi-

mal segments of the great vessels should be carefully assessed for associated injuries. Treatment of acute traumatic aortic injury has traditionally been operative repair, but increasingly patients are being treated with endovascular stent-grafts (Fig. 6). Emergency surgery for treatment of acute traumatic aortic injury has mortality rates of 15 to 29% with higher mortality in the elderly.[23]

PELVIS

Most patients with pelvic fractures are hemodynamically stable. A small percentage, particularly those with unstable fractures, present with hemodynamic instability. Pelvic fractures alone are associated with mortality rates of 5.6 to 15%, but the addition of hemorrhagic shock raises rates from 36 to 54%.24 Death due to hemorrhage frequently occurs in the first 24 hours, and the mortality rate rises with delays in treatment.25,26 Associated organ injuries have been found in 11 to 20.3%,24 injuries that can increase morbidity and mortality. Failure to treat or delay in treatment can result in death due to hemorrhage or abdominal compartment syndrome. Pelvic hemorrhage most commonly arises from fractured bones or disrupted pelvic veins with only 10 to 20% of severe hemorrhage from arterial injury.27 Hemodynamically unstable patients with pelvic fractures require aggressive resuscitation. Treatments for traumatic pelvic hemorrhage include external fixation of unstable fractures, transcatheter embolization, and pelvic packing. Open surgical procedures like packing are not advised due to the loss of the tamponade effect of the contained hematoma, risking large-volume, uncontrolled venous and/or arterial bleeding.28 External fixation apposes bone surfaces and reduces pelvic volume, enhancing tamponade from the enlarging hematoma. This maneuver may stop bleeding from bone surfaces and veins but is unlikely to stop arterial bleeding30 and delays transcatheter embolization. Arterial bleeding at angiography has been associated with a lack of response to initial resuscitation, the pelvic fracture pattern, the amount and location of pelvic hematoma, and active extravasation of contrast at CT.29,31 CT with contrast diagnoses and localizes arterial extravasation from pelvic trauma with a sensitivity of 60 to 90%, a specificity of 85 to 98%, and an accuracy of 87 to 98%.24,31 CT evidence of extravasation in the pelvis is an indication for transcatheter embolization. The internal pudendal artery and superior gluteal arteries are two of the most commonly injured pelvic arteries.25,27 Most arterial hemorrhage originates from branches of the internal iliac arteries. Nonselective pelvic arteriography can be useful to localize and lateralize a site of hemorrhage. Selective arteriography of the internal iliac arteries should follow. Currently accepted indications for transcatheter embolization include active extravasation, arterial branch irregularity or truncation, one or more pseudoaneurysms, and arteriovenous fistula for-



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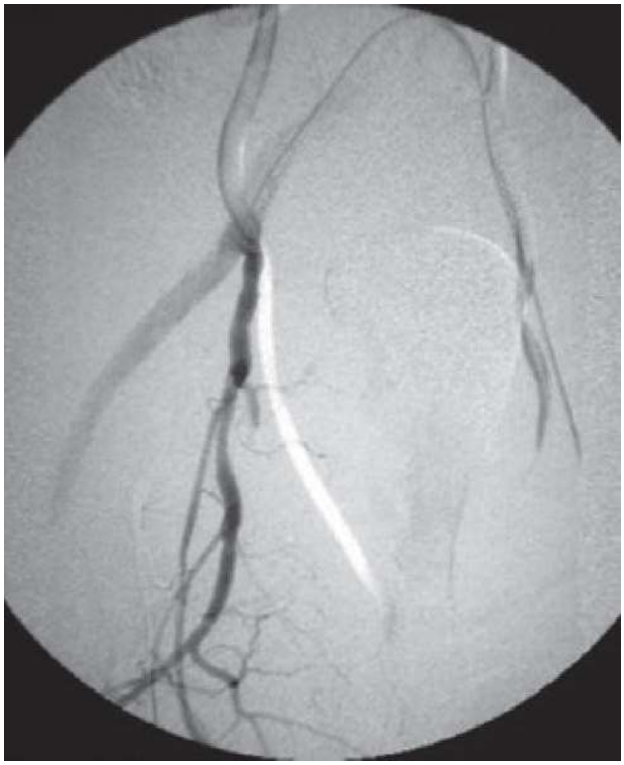

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Figure 7. Right iliac angiogram demonstrating acute extravasation (arrows) from the right superior and inferior lateral sacral arteries (A), post embolization study of the right iliac artery showing occlusion of the posterior division and internal pudendal artery and no extravasation is evident (B).

mation (Fig. 7). Transcatheter embolization of pelvic trauma that is performed early, within 3 hours of presentation, has been shown to lower the mortality rate. Overall, angiography is required in fewer than 10% of patients with pelvic trauma. When angiography is performed, extravasation is documented in approximately one half of patients; in such cases, transcatheter embolization is warranted.

The chosen embolic agent and technique should provide hemostasis while preserving normal vessels and collateral flow where possible. Gelfoam and micro-embolic particles has been the agent of choice due to its temporary nature. Coils, however, may be appropriate for single arterial abnormalities and for distal to proximal embolization across the neck of a large vessel pseudoaneurysm. Distal gelfoam embolization from a proximal catheter position may be necessary if the patient is unstable, selective catheterization is overly time-consuming, or there are multiple arterial injuries in the supplied region. Proximal embolization with coils to decreased pulse pressure to a site of bleeding is not generally successful due to the robust pelvic collateral network. It is important to evaluate the contralateral internal iliac artery to exclude continued hemorrhage from collaterals or additional sites of bleeding. Success rates for transcatheter embolization range from 85 to 100% with mortality rates of 17.6 to 47% despite successful embolization.24 Lower mortality rates have been associated with early embolization.25 Higher mortality has been seen in older patients and patients with greater hemodynamic compromise and concomitant injuries.25,29

EXTREMITIES

The extremities are frequently injured in trauma, particularly penetrating trauma from gunshot and stab wounds, but arterial injuries can also occur in blunt trauma, typically due to crush injuries, tissue disruption, joint dislocation and laceration from broken bones or penetration by external objects. Currently, most patients with hard signs of vascular injury or evidence of compartment syndrome undergo immediate surgery. Delays in treatment of major arterial injuries have been associated with the need for amputation. Early recognition with vascular repair has improved limb salvage.32,33 Catheter angiography is indicated in cases of known or suspected peripheral vascular injury when the location of the injury is not certain, when multiple injury sites may be present, when the diagnosis requires confirmation, or when transcatheter treatment may be the therapy of choice. Angiography should begin with a nonselective injection of the thoracic arch for upper extremity evaluation and the abdominal aorta or ipsilateral iliac system for lower extremity evaluation. A complete evaluation will often require selective and possibly sub-selective catheterization of the affected extremity. Imaging at the injury site should be performed in at least two projections as subtle injuries and intimal tears may be visible only on one view. Major angiographic findings include active extravasation, large pseudoaneurysms, and arterial occlusion or transection (Fig. 8). Minor angiographic findings include vessel narrowing or displacement by hematoma, spasm, obstruction of minor noncritical branches, small pseudoaneurysms or arteriovenous fistulas.

Transcatheter treatments include balloon occlusion, embolization, and endovascular repair with

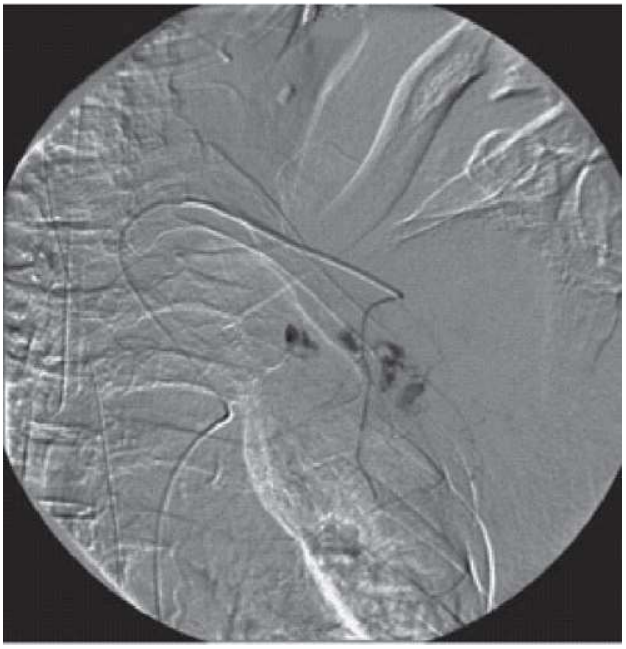

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Figure 8. Active extravasation of the left brachial artery (A), treated with transcatheter coil embolization (B).

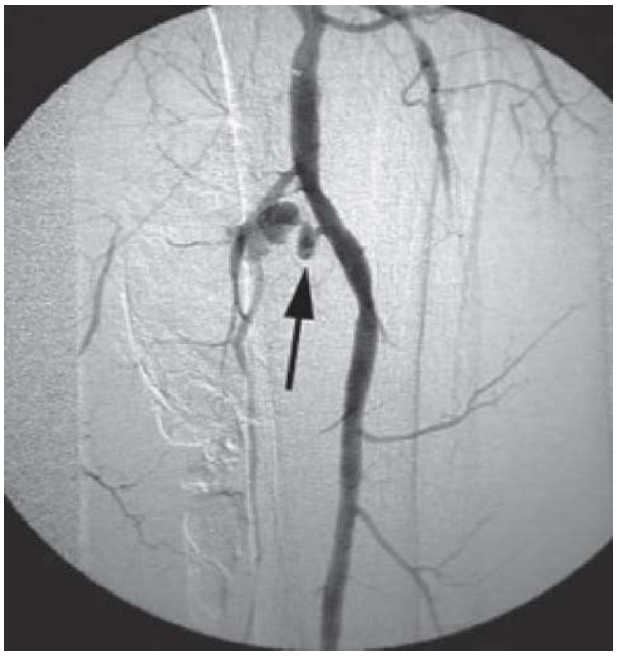

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Figure 9. Left lower extremity angiogram shows extravasation (arrow) from the proximal part of the peroneal artery (A), after embolization of the left peroneal artery with detachable microcoil (arrow) no further extravasation is identified (B).

stent-grafting. Injuries of the aorta or large proximal extremity vessels like the subclavian artery or superficial femoral artery are particularly life-threatening and balloon occlusion can be particularly helpful. Coils are often the best agent for embolization of small vessel injuries (Fig. 9). An appreciation of the collateral circulation to the distal extremity is necessary to determine the safety of and method to avoid reflux of particles causing nontarget embolization. Though arterial transactions, dissections, and occlusions have traditionally been repaired surgically, there has been increasing interest in endovascular repair using stent-grafts.33 Reports are available on endovascular treatment of the aorta,23 the carotid artery,34 the subclavian artery,35 the brachial artery,34 and the iliac arteries.32 Many of the reported repairs using stent-grafts occurred when operative repair was associated with a greater than normal difficulty or there was an immediate need for cessation of hemorrhage.35 There are little data on long-term utility and safety of this treatment. The choice of stent-graft should also take into consideration the location of the injury and the potential for external compression, which could crush or deform a stent-graft. CT-angiography is increasingly useful in the evaluation of extremity arterial injury and is replacing catheter angiography in some settings.33 CT-angiography has a sensitivity of 90 to 95.1% and a specificity of 98.7 to 100% for detection of extremity arterial injury.35 Catheter angiography can typically be performed if additional information is needed.

CONCLUSION

Trauma leaders worldwide show a growing interest in using endovascular tools in trauma resuscitation, hemorrhage control and definitive injury management. Interventional radiology has much to offer in the evaluation and treatment of traumatic injuries. Current literature suggests that this role may expand in time due to desire for organ preservation and avoidance of surgery as well as due to improvements in transcatheter equipment. A solid understanding of the benefits and risks of the different transcatheter therapies is required to provide patients with the best care possible. Effective integration with surgery and emergency medicine requires adequate staffing, organized multidisciplinary evaluation and direct communication with quick response times. Customized hybrid operating rooms equipped for resuscitation, angiographic intervention, imaging capability, and surgical management of trauma patients are becoming the wave of the future for delivering expedited multidisciplinary care. Continued vigilance on the part of the trauma and surgical communities to incorporate the interventionalist into the trauma team is required. Embolization represents a safe and effective technique for rapidly achieving hemostasis. Interventionalists welcome this complimentary role in trauma care that allows for not only definitive treatment of vascular injuries but also for selection of those patients who may ultimately experience failure of conservative management. A therapeutic alliance between trauma surgeons and interventional radiologists will advance the standard of care for trauma.

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No conflict of interest