Special Considerations for Embolization in Trauma Cases

Clinical indicators and arterial embolization techniques.

BY JASON SALSAMENDI, MD; DAVID QUINTANA, MD; ISSAM KABLY, MD; AND GOVINDARAJAN NARAYANAN, MD

One of the most preventable causes of death in abdominal and pelvic trauma is arterial hemorrhage that goes untreated or unrecognized.[1] Over the last decade, radiology has undergone many advances, particularly in noninvasive imaging and interventional angiography, such that critical arterial hemorrhage is both recognized and treated faster, often with life-preserving results. The cornerstone of arterial hemostasis is early intervention, whether via endovascular techniques, open laparotomy, or a combination of both. Early intervention requires a highly sensitive and specific diagnostic study that can be performed and interpreted quickly.

In the past, arterial injuries were largely identified during diagnostic angiography, which was both time-intensive and invasive. With technological advancements in computed tomography (CT), CT angiography (CTA) has essentially replaced traditional diagnostic angiography to evaluate vascular injury. Patients who are hemodynamically stable have traditionally foregone laparotomy and are assessed with CTA and managed nonoperatively. Angiography has been reserved for these patients, yet with interventional techniques evolving over the last decade, embolization has become integrated in the management of both the nonoperative and operative patient.[2-5] Further advances in endovascular techniques have allowed tremendous strides in the management of the unstable patient, and in the appropriate clinical setting, many leading trauma centers have utilized arterial embolization as a component of primary resuscitation.[1,6-9]

In short, interventional radiology plays a major role in the diagnosis, treatment, and management of the trauma patient. Interventional radiology requires a multidisciplinary approach in which the trauma surgeon and interventionist understand both its indications and limitations.
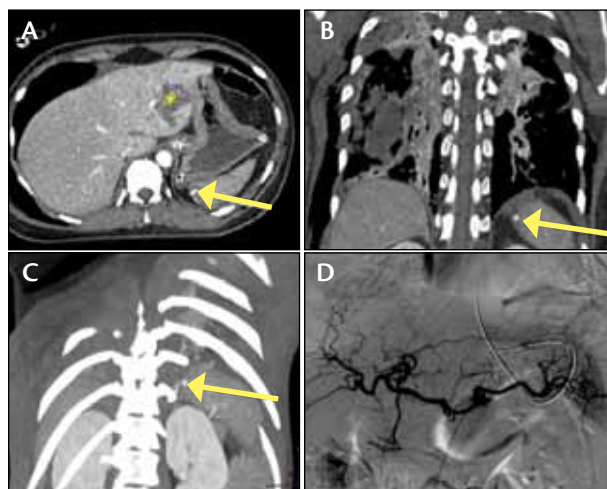
Figure 1. Axial (A) and coronal (B) contrast-enhanced CTA through the level of the spleen demonstrate a contained, well-circumscribed hyperdensity along the peripheral aspect of the spleen, suggesting an intraparenchymal splenic pseudoaneurysm (arrow). Multiple hyperdensities at this level confound the diagnosis; however, an oblique maximum-intensity projection (C) confirms the presence of a splenic pseudoaneurysm (arrow). Also noted is parenchymal hematoma (asterisk) involving segment II of the liver, along with significant pulmonary contusion and subcutaneous emphysema (B). Celiac angiography (D) shows the splenic pseudoaneurysm (arrow) with no active extravasation and patent hepatic and splenic vasculature.

CTA

CTA is typically reserved for trauma patients who are hemodynamically stable. Hemodynamically unstable patients undergo resuscitation, and once vital signs are stabilized, CTA is performed. Development in CT technology has pushed the envelope, however, and CTA is being performed on less stable patients due to advancement in multidetector CTA technology, which has decreased time of acquisition and allowed faster localization of active hemorrhage.[10,11] State-of-the-art multislice scanners not only provide improved temporal and spatial resolution but can also acquire total body images in < 1.5 seconds, which is faster than traditional plain chest and pelvic radiographs.

Multidetector CTA acquires isovolumetric data, enabling the interpreter to reconstruct images in an infinite number of planes. Multiplanar reconstruction and maximum-intensity projections aid in confirming suspected vascular lesions and uncover vascular injuries that may be obscured by adjacent hyperattenuating bone or foreign bodies (Figure 1). CTA does have its limitations. It is important to understand that current CTA imaging is only a snapshot in time and may not detect all vascular lesions that are present.

TRANSCATHETER ANGIOGRAPHY

Angiography confirms 80% to 90% of CTA findings suspicious for arterial injury, yet presents a continuous diagnostic challenge. Active hemorrhage and vascular injury may be subtle, and the appearances of these lesions differ on angiography from CTA.[12] Contrast extravasation is seen as a persistent blush of contrast on angiography that appears earlier than the venous phase and fails to wash out in the delay phase. Pseudoaneurysm is diagnosed as a contained saccular outpouching that has equal density to the adjacent vessel and no evidence of extravasation. Abrupt arterial truncation indicates transection and/or occlusion of the vessel.

When a discrepancy between CTA and angiography manifests, it is important to determine whether it is due to the cessation of arterial bleeding or if vasospasm, the physiologic response to hemodynamic instability, is masking the vascular injury. If active hemorrhage is highly suspected and diagnostic angiography does not locate the lesion initially, provocative angiography may be warranted to reveal contrast extravasation. Nitroglycerin is a safe agent in a trauma setting due to its short half-life of 3 minutes. Its effect allows the interventionist to identify potential life-threatening hemorrhage yet is brief enough to typically not cause further hemodynamic demise. If a discrepancy persists after provocative angiography or if there is a high clinical suspicion of hemorrhage in the absence of CTA, prophylactic embolization may be performed. It is important to con-
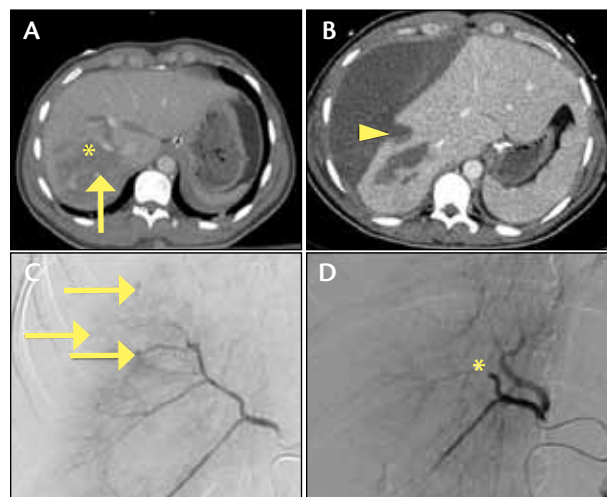

Figure 2. Axial contrast-enhanced CTA (A) shows an extensive hepatic parenchymal hematoma involving segments 7 and 8 (asterisk). There is no active extravasation; however, a contained pseudoaneurysm (arrow) is visualized posteriorly. Repeat CTA 1 month later (B) showed expansion of the hematoma into the liver capsule (arrowhead), causing sudden decompensation. The patient was emergently taken to the angiography suite, and angiography (C) confirmed multiple pseudoaneurysms (arrows), which were subsequently embolized with gelfoam. Postembolization angiogram showed cessation of blood flow to one of the branches of the right hepatic artery, and no evidence of persistent pseudoaneurysm or active extravasation (D).

sider spontaneous cessation of arterial hemorrhage or that hemorrhage may be from a venous source.

TRANSCATHETER EMBOLIZATION

When considering vascular injury, a vast array of tools is available, and a good foundation in angiographic techniques is required. The main agents discussed in this article are stent grafts, occlusion balloons, and embolic agents (both liquid and solid). A stent graft may be used to stop arterial bleeding as well as preserve native arterial flow to the distal organs and tissues. The successful use of a stent graft requires a suitable artery, and therefore, a stent graft cannot be used for every vascular lesion. Vessels should be ≥ 5 mm and should follow a relatively straight course; tortuous vessels are not amenable to stent grafts due to migratory risk. Furthermore, bifurcating vessels are not candidates for stent grafts for similar reasons, as well as risk of branch occlusion; they should also be avoided in young patients due to in-stent stenosis from neointimal hyperplasia. Arteries that are ideal for stent grafts include the external iliac and superficial femoral arteries. Occlusion balloons are typically used as temporizing measures as a
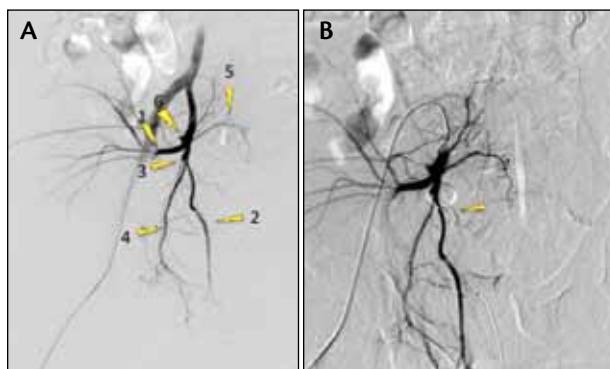
Figure 3. Selective angiogram of the right IIA (A) demonstrated (1) superior gluteal (posterior); (2) internal pudendal (anterior); (3) obturator (anterior); (4) inferior gluteal (anterior), which is truncated; (5) lateral sacral (posterior); (6) iliolumbar (posterior), which is also truncated (numbered in decreasing incidence of injury). Subsequent selective angiography after embolization (B, arrowhead) of the inferior gluteal artery demonstrates no active extravasation.

bridge to surgery or as definitive endovascular treatment in rapid exsanguination.

Embolization can be performed with coils, vascular plugs, gelfoam pledgets, particles, liquid embolics, or a combination of these. Coils function as embolic agents by inducing thrombosis, not mechanical occlusion; the thrombogenic effect is enhanced by Dacron wool tails that are incorporated in the coil.[13] These agents are very effective in proximal embolization and can also be used in sandwich techniques. The sandwich technique is typically used in regions of potential collateralization, such as hepatic or splenic arterial injury. Situations in which the sandwich technique is useful are discontinuous flow in a ruptured hepatic artery or isolated pseudoaneurysm of the splenic artery. Coils and vascular plugs may also be used in cases of arteriovenous fistula or bleeding refractory to other embolic agents. The major disadvantage of coil or vascular plug embolization remains that once proximal embolization is performed, distal access to the vessel is blocked; therefore, repeat endovascular intervention is not possible.[13,14]

Gelfoam is another embolic agent, which is water-soluble and can be prepared rather quickly. It is a temporary embolic agent that is completely absorbed by the body. The arterial vessel typically recanalizes within 2 to 3 weeks.[13] It is effectively used in regions of multiple pseudo-aneursyms and extensively used in pelvic trauma, following arterial flow distally to seal active hemorrhage quickly.[15]

Embolic particles are sometimes used in the trauma setting. Particles are available in many different sizes; however, those that are frequently used in trauma range from 500 to 700 and 700 to 900 μm. Although not as frequently used, liquid agents are also very effective embolic materials. N-butyl

cyanoacrylate (n-BCA) (Trufill Liquid Embolic System, Codman Neurovascular, Raynham, MA) and ethylene-vinyl alcohol copolymer (Onyx Liquid Embolic System, Covidien, Mansfield, MA) are two common liquid embolic agents. Once n-BCA is injected, the microcatheter must be quickly removed from the vessel lumen to prevent catheter-vessel wall adherence.[16] In general, liquid and particulate embolic agents should be avoided in the spleen and inferior gluteal artery to reduce the incidence of abscess and sciatic nerve injury, respectively.[13]

PITFALLS FOR THE INTERVENTIONIST

Pitfalls may arise, even for the most experienced interventional radiologist. A sound understanding of potential variations of normal visceral and pelvic vasculature is essential to master and may prevent treatment failure. Traditional anatomy of the celiac trunk is only present in 70% of patients. Although the common hepatic artery arises from the celiac trunk in 95% of patients, the arterial vasculature of the liver is anatomic in only 55% of the population. Although numerous variations exist in visceral and pelvic vasculature, three major anomalies are of most importance when searching for angiographic extravasation (Table 1). First, the dorsal pancreatic artery arises from the celiac trunk in 10% of patients and should not be mistaken
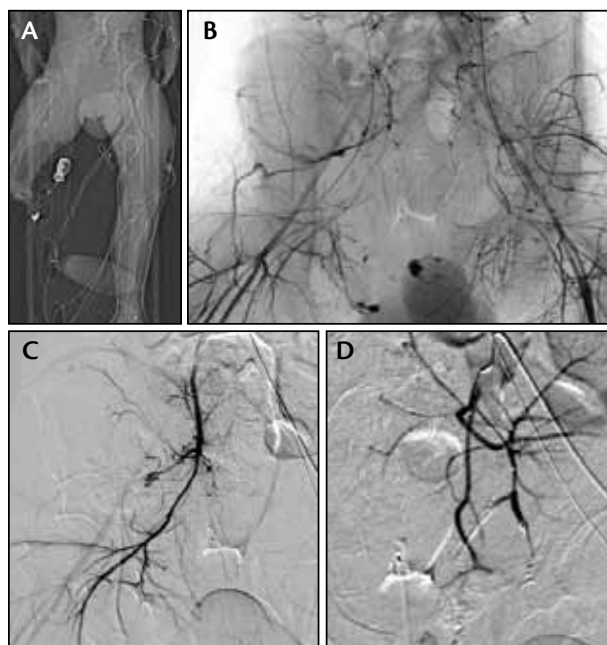
Figure 4. Multiple, bilateral synchronous arterial injuries with active extravasations. Scout view, demonstrating open-book pelvic fracture (A). Pelvic angiogram shows bilateral pelvic extravasation sites (B). Right internal iliac angiogram, postembolization (C). Left internal iliac angiogram, postembolization (D).

TABLE 1. VISCERAL ARTERIAL VASCULATURE[a]		
Vessel	**Arterial Variant**	**Frequency**
Celiac	Celiac origin of left gastric artery (LGA), common hepatic artery (CHA), and splenic	70%
	LGA, CHA, dorsal pancreatic artery, and splenic with celiac origin	10%
	Aortic origin of LGA	2%
	Celiac origin of LGA and splenic only	3%
Hepatic	Right hepatic artery (RHA) and LHA originating from CHA	55%
	Replaced RHA	12%
	Accessory RHA	6%
	Replaced left hepatic artery (LHA)	11%
	Accessory LHA	11%
	RHA originating from superior mesenteric artery; LHA originating from LGA	2%

[a]Adapted from Moore HM, List A, Holden A, et al. Therapeutic embolization for acute haemorrhage in the abdomen and pelvis. Australas Radiol. 2000:44;161–168.[15]

for hemorrhage. Second, in 12% of patients, the right hepatic lobe is supplied by a replaced right hepatic artery, which arises from the superior mesenteric artery. Finally, in pelvic angiography, the obturator artery may arise from the common femoral or inferior epigastric arteries in 20% of individuals, requiring selective angiography of the external iliac artery.[15] An initial nonselective angiogram or previous CTA imaging is usually sufficient to diagnose these anomalies.

Angiographic interpretation is also a potential source of problems. In pelvic angiography of the male patient, it is important to distinguish between active extravasation and cavernosal blush. Differences may be subtle; however, consequences from penile artery embolization are significant, especially in young patients. It is important to understand that the cavernosal blush is typically midline or below the pubic symphysis, arises from the internal pudendal artery, and completely washes out, while active extravasation will persist through the delayed phase.

Another potential downfall is small-vessel arterial truncation from obstructive thrombus. These lesions may also be extremely subtle; however, if the angiogram is not meticulously examined, arterial truncation can be easily missed. As mentioned previously, the hemodynamic status of the patient significantly affects the appearance of diagnostic angiography. Vasospasm may temporarily cease active hemorrhage, and if extravasation is not identified, delayed hemorrhage can result in further demise.

SOLID ORGAN INJURY
Splenic Trauma

The spleen is the most commonly injured abdominal organ in blunt abdominal trauma. In fact, 97% of trauma surgeons consider hemodynamic instability an indication for emergent splenectomy in blunt splenic injury.[1] The current standard of care for splenic trauma in hemodynamically stable patients is nonoperative management.[5,12,17] Nonoperative management fails in 12% to 15% of splenic trauma, and it has been shown that early embolization reduces these rates.[5,17,18] Embolization is additionally advantageous for splenic salvage, with reports demonstrating salvage rates of above 85%.[5] Yet, there is no uniform consensus for indications for angiography or embolization in splenic trauma. Some strongly advocate angiography for all splenic injuries, whereas others reserve angiography for high-grade solid organ injury, presence of vascular injury on CTA, and/or large hemoperitoneum.[5,13]

Splenic embolization can be performed proximally in the splenic artery, distally within intraparenchymal branches, or approached with a combination of both. Proximal embolization is preferable by many interventionists, although outcomes for both proximal and distal embolization are similar.[17] Proximal techniques execute hemostasis by decreasing the arterial pressure from the head to the spleen. It has a decreased risk of infarction due to the preservation of collateral flow; however, there is a concern of the overall function of the spleen after embolization, as the spleen is rendered globally ischemic. The proximal technique is used for multiple vascular injuries or high-grade parenchymal injury. Coils or vascular plugs are typically deployed in the splenic artery distal to the pancreatic vessels. Distal embolization is used in patients with isolated vascular injury or lower-grade splenic injury.[5] A major advantage of the distal technique is preservation of splenic function. Gelfoam slurries are usually used, because, theoretically, the temporary

agent has lower risk of abscess formation than that of permanent embolic agents, such as particles.

Hepatic Trauma

The liver is the second most commonly injured abdominal organ in blunt trauma. Because of the exocrine function of the liver and its anatomic complexity, there is a significant risk of complication, as trauma can cause venous, arterial, and even biliary injury. As a result, more than 85% of trauma-related liver injuries are treated with some sort of intervention. Most hepatic bleeding is from low-pressure venous hemorrhage,[19] yet arterial and biliary injuries are of most significance to the interventionist. Higher AAST (American Association for the Surgery of Trauma) grade increases the risk of arterial and biliary injury and may raise the need for early intervention.[2,20,21]

Furthermore, high-grade hepatic injury and hemodynamic instability often require a multidisciplinary surgical and endovascular approach, with operative management primarily performed and postoperative embolization adjunctively used for remaining arterial hemorrhage.

The morbidity associated with embolization and subsequent liver-related complications is not completely understood, as there is overlap with trauma-related complications. However, the efficacy of embolization for severe hepatic injury has been well established, with success rates of 85% to 100% and a significant mortality benefit.[4,9] Furthermore, recent studies have demonstrated no significant difference in hepatic morbidity with or without embolization.[4,22] Embolization techniques used in hepatic trauma are similar to techniques used in splenic trauma. Due to the rich collateral network of arterial vasculature in the liver, sandwich techniques (see Transcatheter Embolization section) are used more often in hepatic trauma. Coil embolization and liquid embolic agents are also commonly used in the liver.

Complications related to hepatic trauma can be divided into early and late manifestations. Persistent bleeding is the most common early complication, which can occur in up to 9% of conservatively managed patients.[23] It is important to distinguish between active bleeding and delayed bleeding in patients with follow-up CTA. Active arterial hemorrhage can be treated with embolization, while delayed hemorrhage may require operative management.

Severe complications with hemobilia typically manifest late in the patient's course. This is a result of deep arterial injury, usually a pseudoaneurysm, which communicates or ruptures into the biliary tree, resulting in extensive clot burden, obstructive cholangitis, and possible exsanguination (Figure 2). The mortality of untreated hemobilia reaches 60%, and therefore urgent angiography and embolization are required.[23] Finally, gallbladder and biliary necrosis is rare

in the trauma setting, unlike hepatic arterial embolization in hepatocellular carcinoma.[4,23] This is likely due to normal hepatic parenchyma and preserved collateral flow in the majority of the trauma population. The risk of gallbladder necrosis may increase in trauma patients with a history of cirrhosis and/or hepatocellular carcinoma and should be strongly considered.

Renal Trauma

The incidence of renal injury in blunt trauma is approximately 2%, and blunt renal artery injury is even less common, seen in < 1% of blunt trauma patients.[24] Renal injuries are almost never isolated in blunt trauma; typically, the spleen and liver are injured first. Most injuries to the kidney are minor. More than 80% are small hematomas or lacerations with an intact capsule, which can be managed conservatively. Of patients with renal lacerations, 17% extend beyond the capsule, and 7% of these have some sort of communication with the collecting system,[15] which may require intervention. Patients with high-grade injury risk renal dysfunction, renovascular hypertension, or even renal failure. Therefore, although there is no unified consensus for the management of renal injury, higher-grade renal injuries typically receive intervention. Grade II through IV parenchymal injuries are managed in a multidisciplinary approach with angiography and/or surgery with an attempt at renal salvage, whereas grade V parenchymal injuries are by and large managed surgically, many times with nephrectomy.

The renal vasculature differs from that of the liver or spleen, as the kidneys depend on end arteries for blood supply due to poorly developed collaterals. While proximal embolization and sandwich techniques are favored in the liver and spleen, alternative approaches are required in the kidney to preserve renal function. Subsequently, peripheral embolization techniques have been developed, selectively embolizing as distally as possible. These techniques typically require a coaxial approach with microcatheters to get as selective as possible and minimize the risk of parenchymal infarction. Microcoils and liquid embolics, such as n-BCA, are commonly used for these intraparenchymal arterial injuries. A recent 10-year review demonstrated an embolization success rate of 94% when used as primary management.[24] Severe complications related to embolization are rare. Renal infarction is a relatively common phenomenon; however, adverse sequelae are not typically seen. Renal abscess from progression of infarction, occurs in < 5% of postembolization patients.[12]

PELVIC TRAUMA

Due to the anatomic constraints of the pelvic girdle and the close approximation to the osseous structures, vascular injury is relatively common in patients with pel-

vic trauma. It is the cause of the high mortality rate of > 25% in this subset of patients. Hemorrhagic sources in the pelvis are largely due to venous, osseous, and arterial bleeding. Venous and bone hemorrhage can be successfully controlled with pelvic fixation; however, life-threatening arterial hemorrhage cannot be tamponaded, due to the high-pressure system. It has been reported that 10% to 15% of pelvic hemorrhage is due to an arterial injury, and mortality is substantially increased once an arterial source is identified.[25] Due to the potential increase in the pelvic volume, pelvic fracture results in hemodynamic instability in up to 20% of patients.[25]

Pelvic fracture results from lateral compression, anteroposterior compression, vertical shear, or a combination of mechanisms. Anteroposterior compression, vertical shear forces, and combination mechanisms demonstrate a higher failure rate to pelvic fixation alone and typically require angiography. Furthermore, embolization in pelvic trauma boasts success rates of > 87%.[8,25] As a result, embolization has advanced to the vanguard of primary hemostasis in pelvic trauma and has become the standard of care in many institutions. Patients with active extravasation or with pelvic fracture and hemodynamic instability are candidates for angiographic embolization.

The branches of the internal iliac artery (IIA) are the most frequently injured arterial vessels in pelvic trauma (Figure 3). The superior gluteal artery, which originates from the posterior division of the IIA, is the most common site of injury, followed closely by the internal pudendal artery from the anterior division. Embolization is usually performed with gelfoam slurry and/or coils to control hemorrhage (Figure 4). In patients with hemodynamic instability, angiographic contrast extravasation can be difficult to identify due to profound vasospasm. If extravasation is not identified and provocative angiography is not indicated, prophylactic proximal IIA embolization can be performed. The side of the pelvic fracture is identified, and subsequent embolization of the ipsilateral IIA is performed with gelfoam and/or coils. Bilateral prophylactic IIA embolization may be indicated in certain clinical scenarios. This effectively treats arterial hemorrhage and indirectly ceases bleeding from venous and osseous sources in the pelvis. The risk of gluteal claudication and necrosis is significantly increased in this approach and should only be performed in specific critical situations.

Complications of angiographic embolization are generally acceptable, considering the high mortality rates with pelvic trauma; just as in the liver, most complications are difficult to distinguish from actual trauma-related complications. Gluteal necrosis can be seen in unilateral IIA embolization and is more frequently encountered in bilateral embolization of the internal iliac artery. Skin ulceration and necrosis is seen in approximately 10% of pelvic trauma. Recent studies show no significant difference in skin necrosis, sloughing, or peroneal infection rate between embolized and nonembolized patients.[26] Impotence and infertility are also potential risks with embolization of the internal pudendal artery, although there have been no long-term studies to evaluate this. Care must be taken as to not mistake cavernosal blush for extravasation, as this may increase the risk of impotence and infertility if embolized.

CONCLUSION

Interventional radiology has a pivotal role in the diagnosis, management, and treatment of abdominal and pelvic trauma. The major goal in the evaluation of the trauma patient is rapid identification of potentially life-threatening hemorrhage and early intervention. Interventional techniques are used in nonoperative and operative management schemes, in patients who are hemodynamically stable, and those who are unstable. Angiography and surgery are complementary in providing hemostasis, often requiring a multidisciplinary approach. In certain clinical scenarios, angiography may even be considered as an alternative to surgery. Given the complexity of many of these traumatic injuries, which are often multiple, it is imperative both to understand the indications for such interventional techniques and to prepare for the inevitable trauma-related complications that may require further intervention.

Within interventional radiology, much emphasis has been placed on the design of newer angiography suites, which are becoming integrated into the emergency room layout for easier access. Furthermore, some leading institutions are combining computed tomography machines with angiography suites to reduce the time delay between diagnosis and intervention. Ultimately, as the field of interventional radiology progresses, research and further investigation of techniques specifically for the trauma population are needed, not only to allow for earlier intervention but also to advance patient care and provide the safest, most effective treatment. ■

Jason Salsamendi, MD, is with the University of Miami School of Medicine, Jackson Memorial Hospital, Department of Radiology/Vascular Interventional Radiology Section, in Miami, Florida. He has disclosed that he has no financial interest related to this article.

David Quintana, MD, is with the University of Miami School of Medicine, Jackson Memorial Hospital, Department of Radiology/Vascular Interventional Radiology Section, in Miami, Florida. He has disclosed that he has no financial interest related to this article.

Issam Kably, MD, is with the University of Miami School of Medicine, Jackson Memorial Hospital, Department of Radiology/Vascular Interventional Radiology Section, in Miami, Florida. He has disclosed that he has no financial interest related to this article.

Govindarajan Narayanan, MD, is with the University of Miami School of Medicine, Jackson Memorial Hospital, Department of Radiology/Vascular Interventional Radiology Section, in Miami, Florida. He has disclosed that he has no financial interest related to this article. Dr. Narayanan may be reached at (305) 243-4917.

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