Transcatheter Embolization in the Treatment of Hemorrhage in Pelvic Trauma

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ABSTRACT

Massive hemorrhage related to pelvic trauma is relatively rare, but when it occurs rapid triage to therapeutic intervention is essential for survival. Traditional surgical repairs had limited success. Anatomic and clinical studies indicate that arterial hemorrhage is often identified in patients with hemodynamic instability that do not respond to initial resuscitation. Transcatheter angiography directly identifies arterial injury, and embolization can control retroperitoneal arterial hemorrhage. Stent-graft technology extends the scope of interventional therapy to include rapid and definitive repair of nonexpendable artery injury. Successful management requires coordination between multiple services and the continuation of resuscitative procedures in the angiography suite.

KEYWORDS: Angiography, embolization, trauma, pelvic fracture, hemorrhage

Objectives: On completion of this article, the reader should (1) understand the factors influencing the triage of the pelvic trauma patient for transcatheter embolization and (2) be familiar with the principles and techniques of embolization.

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Interventional radiology can have a major impact on the management of pelvic trauma. Minimally invasive control of hemorrhage, repair of ureteral injury, and drainage of post-traumatic or postoperative abscesses provide effective therapy while respecting the challenged physiology of the polytrauma patient.¹ High-energy trauma is required to fracture the pelvis and commonly results in multiple injuries that complicate management.¹⁻¹⁰ The optimal utilization of image-guided interventional techniques depends on local logistics and requires a close and well-coordinated relationship between the trauma surgeon, orthopedic surgeon, interventional radiologist, and the blood bank.^{4,11-15}

Angiography and transcatheter embolization play primary roles in the treatment of the patient with a severe pelvic fracture and hemodynamic instability. Angiography is a sensitive and specific, minimally invasive diagnostic study for arterial injury and active hemorrhage.¹¹ The angiographic catheter positioned proximally to an injury also allows immediate deposition of metallic coils or particulate materials to occlude the vessel or its distal branches, respectively. The advantages of transcatheter hemostatic interventions include rapid vascular control, remote access with maintenance of normal tissue barriers, and avoidance of general anesthesia.^{1,2,12,13,16-19} Since its introduction in the early

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1970s,^{20,21} accumulated documentation of the safety and efficacy of transcatheter embolization to treat hemorrhage from pelvic fracture has resulted in its acceptance as first-line therapy for traumatic pelvic or retroperitoneal hemorrhage in many centers.^{15,17,22-29}

This article reviews the rationale and indications for angiographic intervention in the evaluation and treatment of hemorrhage from pelvic trauma and discusses embolization technique, efficacy, and potential complications.

INCIDENCE

Transcatheter embolization for life-threatening hemorrhage from pelvic fractures is highly effective. The place of angiography in the management algorithm continues to be controversial due to the low specificity of noninvasive diagnosis, the competing management requirements of polytrauma, and the rarity of injury. Pelvic fractures occur in 3 to 9% of blunt trauma patients.³⁰⁻³² In those patients, retroperitoneal hematoma (RPH) is diagnosed in 13 to 44%,^{33,34} but less than half (6 to 17%) are hemodynamically unstable.^{4,5,12,31,35} Mortality in the pelvic fracture patient ranges from 2 to 23%.^{3-7,17,29,36} In populations with complex pelvic ring fractures, reported mortality rates range from 8 to 39%,^{4,5,37,38} and those that are hypotensive have a 10 to 58% mortality rate.^{4,5,8,29,35,36,39} Of pelvic fracture mortalities, pelvic hemorrhage is the major single cause in up to 74% of patients.³⁵⁻⁴²

Hemorrhage related to pelvic fractures may be life-threatening, but concurrent, more obvious injuries may demand attention. Due to the large energy transfer required to fracture the pelvis, polytrauma is common, and the finding of blood in the chest or peritoneal cavity may complicate triage decisions.³⁷ Complex pelvic fractures are associated with a 45 to 85% incidence of additional injuries, the most common being closed head injury in 26 to 55%.^{3,5-7} Intra-abdominal injury to the liver or bladder is present in 16% of pelvic fracture patients,^{32,43} but this incidence doubles when more complex or unstable pelvic ring fractures occur.^{5,6,32}

Unrecognized blunt pelvic trauma-related hemorrhage remains a leading cause of preventable hemorrhagic trauma death.^{41,44} The challenge is to accurately and promptly diagnose the presence, assess the significance, and identify the source of retroperitoneal hemorrhage in the polytrauma patient.

MANAGEMENT

Diagnosis of a pelvic fracture-related hemorrhage is made by imaging or clinical evaluation. Because identification of an RPH does not affect management unless the patient is hemodynamically unstable or has persistent transfusion requirements, the diagnostic workup is driven by the demands of therapeutic resuscitation. If

hemodynamically stable, an RPH may be identified on computed tomography (CT) scan or during definitive repair of a pelvic fracture, and may be self-limited. Another group is subacute patients that present with reliance on intermittent blood transfusion over 6 to 24 hours, and who had an RPH identified intraoperatively or on CT.

The most complicated and controversial group are the hemodynamically unstable patients who remain hypotensive after initial fluid resuscitation; these comprise 5 to 20% of pelvic trauma patients.^{10,30,45} In this cohort, the relevance of associated injuries and the high premium on the early hours for intervention mandate an algorithmic approach to ensure an efficient and coordinated multidisciplinary effort. Center-specific algorithms for resuscitation and diagnostic workup in various clinical presentations have been published.^{8,22,24,29,36,40,43,46,47} All prioritize the assurance of a secure airway and adequate ventilation through endotracheal intubation. Fluid resuscitation with crystalloids is universal, and, in the absence of an adequate response to fluids, identification of the source of hemorrhage begins with evaluation for intraperitoneal or intrathoracic hemorrhage. Intraperitoneal hemorrhage is identified by fluid on the focused abdominal ultrasound (aka focused assessment by sonography for trauma [FAST]) scan or gross blood return at diagnostic peritoneal tap and lavage (DPL), whereas an intrathoracic source is diagnosed by chest tube output. If either is positive, the patient is taken for operative repair.^{30,40,48} In the setting of pelvic fracture and persistent hypotension, if the chest and abdomen are clear, and external or muscular compartment bleeding excluded, a pelvic retroperitoneal hemorrhagic source is diagnosed by exclusion.

There are generally two therapeutic approaches to treatment of the pelvic fracture-related RPH: (1) angiographic evaluation with embolization^{15,28,29,36} and (2) intraoperative external fixation with or without preperitoneal pelvic packing.^{37,47,49-53} The optimal therapeutic approach remains controversial,^{17,19,52,54} but the decision whether the patient is taken to the operating room or the angiography suite must be made. The choice is somewhat based on the expertise and availability of subspecialty physicians and support staff, but also on beliefs as to whether the source of hemorrhage is arterial or venous.

The benefit of external fixation in the hemodynamically unstable patient is widely accepted^{18,11,14,37,47,50-52} but less well documented.^{19,39,53,55-58} The case for a hemostatic effect from external fixation relies not only on the assumption that the majority of pelvic bleeding arises from torn venous plexuses, but also that venous bleeding is the primary source of hemorrhage in the patient that does not respond to initial resuscitative measures. The fact

that pelvic fracture bleeding is generally self-limited supports a low-pressure venous source; however, the 67 to 82% incidence of positive angiographic findings in patients with large or continued transfusion requirements suggests an arterial source in that subset of patients.^{12,24,26,27,29,30,47,59} Although often quoted as supporting a venous source for pelvic fracture hemorrhage, Huittinen and Slatis reported an autopsy study of pelvic fracture patients that demonstrates the prevalence of arterial supply.⁵⁷ Those authors injected arterial contrast at autopsy to identify the sites of hemorrhage associated with pelvic trauma; in 85% the majority of bleeding was from small arteries at the fracture site.⁵⁷ The need to resolve these differing theories on the source of bleeding has been relieved by the technique of wrapping the pelvis. The benefit of emergent fixation is now achieved in most centers by the rapid noninvasive placement in the emergency room of a folded sheet wrapped tightly around the pelvis to provide fracture stabilization and reduce the increased pelvic volume.^{30,60}

However, even when a high likelihood of pelvic arterial hemorrhage is established, the decision to proceed to angiography may be further complicated in the polytrauma patient with small to moderate amounts of intra-abdominal free fluid that suggests intraperitoneal hemorrhage. The angiography versus operating room dilemma persists. In an unstable patient, time spent addressing a nonbleeding lesion may be costly.¹² Although most algorithms prioritize treatment of any intraperitoneal or intrathoracic injuries due to the minimal tamponade effects in those cavities compared with the retroperitoneum, experience has led some authors to recommend exceptions.

Evers and colleagues suggested that angiography precede laparotomy when the indication was DPL-positive only by cell count.⁴⁵ Eastridge and colleagues¹⁰ found that hemodynamically unstable patients with unstable fractures had a 59% likelihood of major pelvic (versus intraperitoneal) bleeding; of that subset of patients treated with both laparotomy and angiography, survival was best in those that had angiography initially. They suggested that with unstable fracture patterns, angiography be the first intervention even in the setting of hemoperitoneum.¹⁰

The time constraint imposed by the need to mobilize the vascular and interventional radiology (VIR) team was problematic for the utilization of angiography and embolization despite its demonstration as the optimal therapy for pelvic trauma hemorrhage. Early predictors of the need for angiographic intervention were needed. Analyses to predict these patients by pelvic fracture classification generally found that more complex and unstable fractures were associated with higher transfusion rates, and a more frequent need for angiographic intervention.^{6,7} However, these were not sensitive or specific enough to direct management. Blackmore and

colleagues⁴⁸ reported a clinical prediction rule for major pelvic hemorrhage based on immediately available information: initial pelvic radiographs and hemodynamic status. The identified predictors of major hemorrhage were an initial hematocrit ≤ 30 , pulse rate ≥ 130 , obturator ring fracture and symphyseal diastasis displaced 1 cm or more. The presence of three or more of these predictors gave a 66% probability of major pelvic retroperitoneal hemorrhage. This could serve as an early trigger for mobilization of the interventional team. Further, at such a high likelihood of pelvic fracture-related arterial hemorrhage, the need for angiographic embolization could equal or supersede the need for laparotomy.⁴⁸

PELVIC ANGIOGRAPHY

Indications and Contraindications

It was once common dogma that the angiography suite was the last place to send a hypotensive, hemodynamically unstable patient. This is not the case for pelvic fracture patients in hemorrhagic shock and refractory to initial fluid resuscitation. In the setting of life-threatening hemorrhage associated with pelvic fractures, the most effective hemostatic maneuver is transcatheter occlusion of the bleeding vessels. Delay in angiographic evaluation and embolization is associated with dramatic increases in mortality rates.^{17,45} However, to implement a therapeutic strategy of emergent embolization for pelvic fracture-related hemorrhage, the angiography suite must be equipped and staffed to continue resuscitation measures to improve perfusion, diminish acidosis, replenish clotting factors, and rewarm the patient during the procedure.

Clinical indications associated with high sensitivity and specificity of angiography for pelvic fracture-related RPH are: (1) persistent hypotension after a 2-L fluid challenge where intraperitoneal hemorrhage has been excluded, (2) transfusion requirements for a pelvic fracture exceeding four units of blood within 24 hours or six units within 48 hours, (3) a pelvic hematoma in excess of 600 cc or with active extravasation seen at CT, and (4) a large or expanding pelvic hematoma found at laparotomy.^{13,22,29,61} O'Neill and colleagues reported positive findings in all of 35 patients triaged to angiography by these criteria.¹³

Contraindications to angiographic intervention are relative. The most often cited situations are a rapidly expanding hematoma, hematoma ruptured into the peritoneum, and hematoma ruptured through a perineal wound. Once in the operating room, direct packing may be the most expeditious approach; however, the effectiveness may be limited. Once packs establish temporary control, these patients often benefit from urgent transfer to the angiographic suite for transcatheter embolization

of hemorrhage from pelvic arteries that are rarely amenable to surgical control.^{2,11,22,52,53,62,63}

Technique

Percutaneous femoral artery access is obtained on the less involved side (i.e., contralateral to the most severe fracture or hematoma). Access may be difficult and time-consuming if the hematoma spreads into the groin, or if massive fluid resuscitation leads to diffuse edema.⁶⁴ Ultrasound guidance, or a needle with a Doppler stylet (SmartNeedle, Cardiovascular Dynamics, Inc., Irvine, CA), can be useful to locate a deep or clamped-down artery. Alternatively, bony landmarks can guide 21-gauge needle puncture at the junction of medial and middle third of the femoral head at the acetabulum. An axillary, brachial, or radial approach may be used if the groin access is particularly difficult, but this is seldom necessary.

As with the general management of the trauma patient, an angiographic algorithm is helpful. A systematic approach to diagnostic evaluation entails low abdominal and pelvic angiography and selective internal iliac studies. If hemorrhage is identified, it is treated, and then the diagnostic survey continues. If no abnormality is found in the pelvis, the liver, spleen, and renal arteries may warrant study if the clinical situation indicates.

Single-view flush angiography of the pelvis and abdomen often requires two sequences to cover from the renal arteries to the upper thighs (Fig. 1A). Relatively large volume injections may be necessary to ensure adequate visualization of lumbar and external iliac branch vessels. Attention to the degree of opacity provided on a test injection may be instructive. The arteries may be narrow, "clamped down," due to hypovolemic shock, or flow may be rapid in the young hyperdynamic trauma patient. If not intubated and studied during apnea, patient, respiratory, or bowel motion may compromise digital subtraction images; in such a setting, the unsubtracted images should be diagnostic. A rule of thumb is to use the millimeter diameter of the vessel (in milliliters) as the volume per second, for a 2-second injection. Imaging at more than two frames per second is unnecessary unless a high-flow arteriovenous fistula (AVF) is to be evaluated. The study is routinely performed into the venous phase to confirm the blush of contrast extravasation (Fig. 1C, D) (Fig. 2).

Selective internal iliac angiography is mandatory because bilateral and multiple bleeding sites are common (Fig. 2),^{13,57} and do not necessarily correlate with the fracture sites. Additional vessels are subselected in areas of known injuries or when abnormalities are identified on the initial angiograms.^{1,22} Thorough familiarity with the other known injuries and results of any imaging studies is mandatory.

Signs of arterial injury include occlusions, narrowed segments, intimal flaps, filling defects, AVF, and contained (Fig. 3) or free (Figs. 1, 2, and 4) extravascular contrast. Extravasation is diagnosed by irregular collections of high-density contrast outside the vessel wall that persist into the venous phase. Although a lesion may appear contained (Fig. 3), the term "contained pulsatile hematoma" may be more appropriate than the usual "false aneurysm," as there is no wall and these are not chronic or necessarily stable lesions. On a nonselective angiogram, extravascular contrast may appear transiently and fade if contrast is diluted in a large hematoma. If a lesion is suspected, a selective study is necessary to confirm or exclude a source of hemorrhage. It has been claimed that hemorrhage from cancellous bone cannot be identified,⁶⁵ but bleeding from multiple small vessels at fracture sites has the characteristic appearance of clustered round collections of contrast (Fig. 4). Comparison of subtracted and unsubtracted images is useful to distinguish these abnormalities from underlying bony irregularity or overlying bowel.¹ Confirmation with delayed and oblique images will help distinguish between a draining vein and a small focus of extravasation.

Significant Angiographic Findings

Transmural arterial injury that appears as extravasation, an AVF, or a false aneurysm will infrequently heal and, particularly in the clinical setting of persistent transfusion requirements, are generally treated.¹ Although a large amount of contrast extravasation is clearly a problem, small amounts may be equally important. Extravasation from small vessels has occasionally been termed "minor" or "insignificant," and judged to not warrant embolization.¹¹ However, if extravasation is seen, the blood loss is in excess of 0.5 mL/min (or 3 U per day).⁶⁶ Hemorrhage, and its angiographic and clinical manifestations, may be intermittent, as the egress of blood from an artery reflects the changing pressure dynamic between the extravascular hematoma and the intra-arterial pressure. In particular, the amount of extravasation visualized from a particular injury will vary over time with the patient's blood pressure, coagulation status, local degree of arterial spasm, and extent of tamponade by local hematoma and surrounding structures. Injured small muscular branches often occlude spontaneously, but the likelihood cannot be predicted from the angiographic image and may not occur in the coagulopathic patient. If it can be performed safely and expeditiously, even small branches with evidence of hemorrhage should be embolized.

In vessels that are occluded, have irregular narrowing, or have filling defects, the extent of underlying arterial injury is not defined by the angiogram. Transmural injuries can be masked by local thrombus that may

Figure 1 A 74-year-old woman passenger in a motor vehicle crash remained hypotensive despite initial fluid resuscitation. (A) Pelvic radiograph shows acetabular fracture (arrow) and large pelvic hematoma compressing bladder (arrowheads). (B) Computed tomography (CT) scan depicts caudal extent of the hematoma with active extravasation within (arrow). (C) Early and (D) late flush angiographic images of pelvis is shown. Note contrast extravasation (arrow) over left symphysis pubis. (E) Selective left internal iliac angiogram shows focus of extravasation from internal pudendal (arrow). (F) Late image from selective left internal iliac injection was taken after internal iliac Gelfoam embolization. There is stasis in the anterior division arteries (arrow). However, reflux into external iliac artery and opacification of the inferior epigastric and deep femoral branches were noted with subsequent extravasation at the area of injury (arrowhead). (G) Selective arteriogram shows symphyseal branch of inferior epigastric artery (arrow) with extravasation. (H) Unsubtracted image was taken after microcoil embolization (arrow) of inferior epigastric artery branch. Residual contrast is seen in multiple areas of extravasation (arrowheads). (I) Subtracted image of left iliac arteriogram shows occluded symphyseal branch (arrow at microcoil).

Figure 2 A 20-year-old man, after motor vehicle crash and after open repair of abdominal injury in the operating room, was transferred to vascular and interventional radiology (VIR) due to large retroperitoneal hematoma seen intraoperatively and continued blood requirements. Selective right internal iliac artery digital-subtracted angiogram shows multiple foci of extravasation from visceral and internal pudendal artery branches (arrowheads). These were successfully occluded with Gelfoam slurry.

lyse over time and manifest later as a false aneurysm or free extravasation.^{67–69} The likelihood that a nonocclusive filling defect would later manifest as a transmural injury (false aneurysm) was up to 43% in a series of carotid trauma.^{67,69} The indication to treat traumatic occlusions and mural defects or irregularities is not clear. However, when located in expendable internal iliac artery branches, the safest approach is a liberal application of embolization. If the artery is not expendable (i.e., aorta, common or external iliac, common femoral), an injury that is not clearly transmural may be observed, treated with a stent or stent-graft, or surgically repaired. Those that are not immediately repaired require imaging follow-up until healed.⁶⁸

Embolization

Embolization is the most direct and widely employed therapy for pelvic fracture-related hemorrhage unresponsive to fluid resuscitation.^{10,15,17–19,24,26–29,36,45} The method of embolization and the type of embolic material are based on the size of the artery, the collateral supply to the tissue, and the location of the lesion. The goal of embolization is the rapid control of hemorrhage from sites of injury with maximal preservation of normal vascular beds.

There are four basic types of lesions: (1, 2) distal branches with and without collateral supply and (3, 4)

large branches with or without collateral supply. Without collateral supply, an injured large vessel (e.g., common iliac artery) is not considered expendable and should be repaired rather than embolized, if possible. A distal branch without collaterals (e.g., renal artery branch) should be occluded as close as possible to the lesion to minimize the amount of distal parenchyma that would become ischemic.

Pelvic trauma-related massive hemorrhage most often results from injury to internal iliac artery branches that have extensive collateral supply to their terminal distributions (Figs. 1–4). In these vessels, proximal embolization with coil occlusion is not effective. Lessons from early surgical failure to control hemorrhage by ligation of the internal iliac arteries are instructive.^{4,63,70} The hemodynamic effect of bilateral internal iliac ligation as described by Burchell was a decrease in pulse pressure of 85%, but blood flow decreased only 48%. Failure was due to the extensive collateral circulation to the distal internal iliac artery branches.^{71,72} A thorough understanding of this pelvic collateral anatomy is essential for effective transcatheter embolization.

The pelvic arterial collateral circuits were described by Brotman and colleagues⁷² as three loops:

1. Posterior loop of medial sacral and lumbar arteries that communicate with the posterior division of the internal iliac artery (the superior gluteal, iliolumbar, and lateral sacral arteries) (Fig. 4)
2. Anterior loop, which consists of internal pudendal, obturator, and visceral (anterior division) internal iliac artery branches that communicate with their contralateral counterparts, as well as with the inferior epigastric artery, gonadal artery, superior rectal artery, and branches of the deep femoral artery (Fig. 1)
3. Lateral loop between the superior and inferior gluteal arteries that communicate with deep femoral and circumflex iliac arterial branches

The extensive collateralization in the pelvis diminishes the risk of infarction, but mandates very peripheral obstruction (beyond the collateral communications) for effective occlusion of flow to distal injured branches. In the majority of blunt pelvic trauma arterial bleeding, this is most efficiently accomplished by flow-directed particulate embolization of the internal iliac artery branches. Occlusive particles may be deposited quite proximally to the branches that are injured and are carried by the blood flow to the site of injury (Fig. 1C–F). This approach is nonselective and results in occlusion of some noninjured vessels; on the other hand, multiple vessels in a traumatized vascular bed can be very rapidly treated (as compared with multiple selective catheterizations).

Although collaterals may maintain flow beyond an artery that is controlled proximally, the overlap in the distributions of distal branches mandates angiography of

Figure 3 After an automobile crash, this 62-year-old woman was referred to vascular and interventional radiology (VIR) for recurrent hypotension despite initial fluid and blood product administration. (A) Low abdominal aortic angiogram shows large area of extravasation from inferior gluteal transection (arrow). (B) Selective left internal iliac angiogram identifies superior gluteal artery (short arrow) and precisely localizes the lesion in the inferior gluteal (long arrow). (C) Transcatheter coil embolization shows coils deployed proximally (arrow) and distally (arrowhead) to the injury. (D) After embolization, internal iliac angiogram shows no flow into the inferior gluteal artery.

the collaterals even after particulate (distal) embolization. This is to exclude collateral supply not to the embolized artery, but to a second injury at the same site that is supplied by the terminal branches of the collateral artery (Fig. 1E–H).

The embolic medium of choice is gelatin sponge (Gelfoam, Upjohn, Kalamazoo, MI). It is ubiquitous, inexpensive, and temporary. Although there are many methods to prepare particulates from the $0.3 \times 3 \times 5$ -cm slab, homogeneous sizes without shavings are desired. When moist, they become compressible, flow into distal vessels approximately half their diameter, and there they produce a mechanical occlusion. Gelfoam powder requires less preparation, but it should be avoided; tissue necrosis is not the goal, and small particles (50 to 250 μm) can occlude arterioles and cause skin necrosis or nerve injury. The Gelfoam may be hand cut into 2- to 3-mm pledgets, and injected into the target vessel through a tuberculin syringe (1 mL) in 0.1- to 0.3-mL aliquots,¹ but this is time-consuming. In the unstable patient with multiple distal branch injuries, a slurry may be rapidly mixed by forcing coarsely cut contrast-soaked Gelfoam through a three-way stop-cock between two 20-cc sy-

ringes. One large syringe is left on the stop-cock as a reservoir for the resultant 1- to 3-mm diameter particles, which are then injected with a 1- to 3-mm syringe under fluoroscopic guidance.^{73,74} The size of the syringe depends on the flow rate in the artery; as flow slows, smaller volumes allow better control to avoid reflux. Alternative particulate emboli are polyvinyl alcohol (PVA) (Contour, Boston Scientific/Medi-tech, Watertown, MA) and tris-acryl particles (Embospheres, Biosphere Medical, Rockland, MA). These permanent particles are packaged in a calibrated range of sizes (50 to 1200 μm) which may be used to ensure antegrade flow-direction to a peripheral injury in small arteries.

Focal injuries in large expendable vessels (i.e., internal iliac trunk, proximal superior gluteal) are treated with focally occlusive devices (metallic coils) (Cook, Inc, Bloomington, IN) or Amplatzer plugs (AGA Medical Corp, Plymouth, MN), with the goal of isolating the injured segment by proximal and distal arterial occlusion (Fig. 3). The local distal exclusion blocks retrograde collateral flow to the injury, with preservation of the more distal vascular beds, which are perfused by collateral flow. The stainless steel or platinum coils have

Figure 4 This inebriated 42-year-old man presented hypotensively with falling hematocrit after he fell down a couple flights of stairs. (A) Computed tomography image shows fracture in right iliac (arrow) and adjacent hematoma with active extravasation (arrowhead). (B) Selective right internal iliac angiogram shows extravasation at level of fracture from iliolumbar branch (arrow). (C) Selective right fourth lumbar angiogram shows collateral supply to the injury at the fracture site (arrow), as well as a more distal lumbar injury with extravasation (arrowhead).

Dacron filaments attached that increase their thrombogenicity through the adhesion of platelets and red blood cells. These devices may be packed tightly to become physically obstructive (Fig. 1H), but otherwise rely on an intact coagulation mechanism to produce a thrombus (Fig. 3C). In trauma patients, occlusion should be assured by reevaluation after 10 minutes, and if flow persists, placement of additional coils or a particulate embolic may be necessary.

Focal transmural injuries in large-conduit, non-expendable vessels (i.e., aorta, common iliac, external iliac, common femoral artery) are rare, but carry a high mortality risk.⁷⁵ Repair, either by open surgical methods or with a stent graft is the preferred treatment.⁷⁶ If a stent graft is not immediately available, temporary he-

mostasis can be obtained with an occlusion or angioplasty balloon at or proximal to the lesion; this permits an orderly transfer to the operating room for repair.⁷⁷

Although expendable, the lumbar, circumflex iliac, middle sacral and inferior epigastric arteries warrant an approach similar to the method used for nonexpendable distal branch arteries; that is, subselective catheterization with maximal purchase of the catheter into the vessel before embolization (Figs. 1F-I and 4C). A 4F or 5F catheter may occlude the origin and compromise flow direction of particulates. Micro (3F) catheters (Mass Transit, Cordis/Johnson & Johnson, Miami, FL; Tracker, Medi-Tech/Boston Scientific, Natick, MA) can be placed coaxially through a catheter with an 0.038-inch lumen. Subselective catheterization allows

precision placement of emboli; decreases the risk of reflux into nontarget vessels; and, with retraction of the larger catheter from the vessel orifice, avoids compromise or spasm of the origin of the vessel that would hinder flow direction of the emboli. If flow is limited, even by the small catheter, or purchase is limited (such that the risk of reflux into the common femoral, external iliac, or aorta is increased), microcoil embolization can be used.

Embolization is terminated when injections begin to reflux, when there is stasis of contrast medium injected in the desired vessel, and when extravasation is no longer seen on fluoroscopy^{1,73}. After a completion angiogram of the treated vessel, collateral arteries to the injured vascular bed are assessed and further embolization performed, if necessary (Figs. 2 and 4).

If successful embolization of the pelvic lesions does not result in prompt hemodynamic improvement, an abdominal aortic angiogram may rapidly evaluate the abdomen for renal, hepatic, and splenic artery injuries. These vascular beds are also amenable to transcatheter embolization therapy.^{16,78,79} In addition, ultrasound reevaluation of the intraperitoneal cavity for delayed bleeding from hepatic veins or mesenteric arteries can be performed.

Complications

The major complication of an interventional angiographic approach to the pelvic fracture-related RPH is failure to control hemorrhage. Rarely, this is due to the high rate of bleeding from extensive injuries and/or delay in presentation to the angiography suite.^{2,13,23} Another rare reason for failure is an inability to gain adequate access to a bleeding vessel from which embolization may be safely performed.¹⁹ The most common complication is recurrent hemorrhage that requires a repeat procedure, which occurs in 5.8 to 7.5% of embolizations.^{18,28} A large proportion of these may be unavoidable, as 82% demonstrated a bleed at a site that had no hemorrhage on the initial study.²⁸ A delayed re-bleed may be due to a missed injury, or, if days after the acute event, it may be due to recanalization of a thrombus before adequate healing of a transmural defect.⁶²

Less common complications of arterial embolization include ischemic necrosis of the rectum or gluteal muscles and peripheral nerve damage with paralysis or paresthesia. Liquid embolics (alcohol, glue), Gelfoam powder (40 to 60 μm particulates), a slurry made from unmoistened Gelfoam (which will have microfragments), and PVA particles < 250 μm in diameter should not be used because these obliterate capillaries or perineural arterioles and produce tissue or nerve necrosis.⁸⁰ Gluteal necrosis is usually only seen with the comorbidity of a degloving injury.²⁴ However, one report of bilateral iliac embolization had a 6%

incidence in patients without a gluteal soft tissue injury.⁸¹

Distal lower extremity ischemia or conduit vessel occlusion may occur from nontarget embolization if the catheter is inadequately seated in the parent vessel, or if the injection of emboli continues beyond stasis and there is reflux back to the parent artery.² Infection of the hematoma, acute respiratory distress syndrome, sepsis, or acute tubular necrosis may be associated with embolization, but it is usually difficult to assess the contribution of embolization or the contrast load in patients that have had multiple diagnostic and therapeutic procedures.⁶²

Bilateral internal iliac embolization raises a concern for impotence. The incidence associated with embolotherapy is unclear because sacral nerve injury resulting from pelvic fractures and associated urethral injuries are frequent comorbidities and independent causes. Ramirez and colleagues compared pelvic trauma patients with bilateral internal iliac artery embolization to a group matched for pelvic Abbreviated Injury Score and the presence of urethral or bladder injuries without embolization. At 1-year follow-up, there was no increased risk of impotence after embolization.⁸²

Results

A positive angiogram is reported in 28 to 100% of studies for traumatic pelvic retroperitoneal hemorrhage, which reflects the variation of indications for angiography.^{11,13,17} Authors that employ criteria of nonresponse to fluid resuscitation or a 2- to 4-U blood transfusion requirement report positive angiographic studies in 75% of patients.^{12,24,27-30,47} Successful transcatheter embolization of pelvic hemorrhage, by the criteria of control of extravasation and a decrease in transfusion requirements, is reported in 84 to 100% of those treated.^{17-19,24,26,27,30,47} Survival is improved if angiography is implemented early, within 5 versus 18 hours, or in patients that received proportionately fewer blood products (9 versus 30 U).^{9,17,19,83} The reported mortality rate remains high at 5 to 35%, with death usually a result of associated injuries or multiple organ failure.^{17-19,24,26,27,30,47}

Although there are no prospective randomized studies, a prospective study by Bassam and colleagues¹⁹ evaluated the efficacy of transcatheter embolization versus external fixation. Fifteen (28%) of 54 pelvic fractures were hemodynamically unstable or had evidence of ongoing hemorrhage as demonstrated by decreasing hematocrit and/or increasing lactic acidosis. Patients with positive DPL entered the algorithm after exploratory laparotomy. Patients with anterior or vertically stable combined fractures were treated with primary external fixation, and those with posterior or vertically unstable combined fractures were treated by transcatheter embolization. Despite more severe fractures and

greater blood requirements before the procedure, the angiography group had fewer complications. No patient that was embolized required adjunctive external fixation, whereas half of the external fixation group required subsequent angiographic embolization.¹⁹

Velmahos and colleagues,²³ in another prospective study, documented the safety and efficacy in 94% of those treated with transcatheter embolization for traumatic hemorrhage. That study identified no clinical characteristics that would reliably exclude all patients who were not bleeding internally. Hence, they concluded that transcatheter embolization "should be offered liberally in patients with selected injuries of the pelvis. . . ."²³

CONCLUSION

Twenty years ago, diagnostic angiography with transcatheter embolization for hemodynamically unstable pelvic fracture patients was an intervention of last resort⁴; now it is often the preferred first intervention.^{10,12,28} Angiography and embolization provide what is likely the most rapid, safe, and effective treatment for pelvic fracture-related arterial hemorrhage. The basis for the persistent controversy regarding transcatheter embolization is the cost in terms of time, when the patient is in angiography rather than the operating room. The historic difficulty of managing an ongoing resuscitation in the angiography suite led many trauma surgeons to prefer intraoperative interventions whenever possible. But technology has improved, and advanced resuscitative efforts can and should continue in the modern interventional suite. With the provision of proper equipment and prompt availability of personnel, interventional radiology has a unique and vital role in the treatment of the pelvic fracture patient with retroperitoneal hemorrhage.

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