Multidetector CT in Vascular Injuries Resulting from Pelvic Fractures: A Primer for Diagnostic Radiologists

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Abbreviations: AP = anteroposterior, APC = AP compression, DSA = digital subtraction angiography, LC = lateral compression

RadioGraphics 2019; 39:2111–2129

https://doi.org/10.1148/rg.2019190062

Content Codes: CT ER VA

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See discussion on this article by Dreizin (pp 2130–2133).

SA-CME LEARNING OBJECTIVES

After completing this journal-based SA-CME activity, participants will be able to:

- Identify the pelvic arterial anatomy and vascular territories at CT.
- Describe the imaging findings of vascular injuries and differentiate an active arterial-venous bleed from a pseudoaneurysm at CT.
- Discuss the role of angioembolization in the treatment of pelvic vascular injury.

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Pelvic vascular injuries are typically caused by high-energy trauma. The majority of these injuries are caused by motor vehicle collisions, and the rest are caused by falls and industrial or crush injuries. Pelvic vascular injuries are frequently associated with pelvic ring disruption and have a high mortality rate due to shock as a result of pelvic bleeding. Morbidity and mortality resulting from pelvic vascular injury are due to pelvic hemorrhage and resultant exsanguination, which is potentially treatable and reversible if it is diagnosed early with multidetector CT and treated promptly. The pelvic bleeding source can be arterial, venous, or osseous, and differentiating an arterial (high-pressure) bleed from a venous-osseous (low-pressure) bleed is of paramount importance in stratification for treatment. Low-pressure venous and osseous bleeds are initially treated with a pelvic binder or external fixation, while high-pressure arterial bleeds require angioembolization or surgical pelvic packing. Definitive treatment of the pelvic ring disruption includes open or closed reduction and internal fixation. Multidetector CT is important in the trauma setting to assess and characterize pelvic vascular injuries with multiphasic acquisition in the arterial and venous phases, which allows differentiation of the common vascular injury patterns. This article reviews the anatomy of the pelvic vessels and the pelvic vascular territory; discusses the multidetector CT protocols used in diagnosis and characterization of pelvic vascular injury; and describes the spectrum of pelvic vascular injuries, the differentiation of common injury patterns, mimics, and imaging pitfalls.

Online supplemental material is available for this article.

Introduction

Pelvic vascular injuries and resultant pelvic extraperitoneal bleeding are important determinants of morbidity and mortality in patients with blunt pelvic trauma. Pelvic bleeds have three potential bleeding sources: arterial, venous, and osseous. Death due to a pelvic injury can be the result of massive or ongoing pelvic hemorrhage that leads to complications such as hemodynamic instability, intractable shock, coagulopathy, or multiorgan failure (1).

The majority of pelvic fractures result from motor vehicle collisions (50%–60%) and falls from heights (20%–30%), and the rest result from industrial or crush injuries (2). The presence of pelvic ring disruption usually suggests that high-energy trauma has occurred. Vascular injuries in patients with pelvic trauma are related to the mechanism and severity of the traumatic force. Two widely used pelvic ring injury classification systems proposed by Young et al (3,4) (Young-Burgess classification) and Tile (5) are based on the magnitude and direction of the force and resultant pelvic instability, which guide management and prognostication. In the Tile classification system, pelvic fractures

TEACHING POINTS

- The presence of a pelvic hematoma is the most common CT finding of pelvic vascular injuries and is seen as an ill-defined area of hyperattenuation at CT in the vicinity of the injured vessel. A pelvic hematoma should be differentiated from contrast material extravasation, because the presence of contrast material extravasation suggests ongoing bleeding. Clotted blood shows CT attenuation in the range of 40–70 HU (mean attenuation, 51 HU), while extravasated contrast material has higher attenuation of 85–370 HU (mean attenuation, 132 HU). The location of the pelvic hematoma helps the radiologist to determine the possible injured vessel on the basis of the course of the vessel and the arterial territories.
- An aberrant anastomotic connection between the obturator artery and the inferior epigastric artery is known as the corona mortis. It is the most important anatomic variation and is present in up to 30% of patients. The corona mortis should be considered as a bleeding source if the internal iliac angiogram does not reveal a pelvic source of the bleeding at digital subtraction angiography (DSA). In such instances, angiography of the external iliac artery should be performed to exclude bleeding from the corona mortis.
- Direct signs of arterial injury at CT include abrupt narrowing or contouring of an artery (eg, intimal injury, thrombosis, vasospasm, or intramural hemorrhage), intraluminal linear filling defects (ie, dissection), focal outpouching (ie, pseudoaneurysm), active contrast material extravasation (ie, transmural injury or transection), arterial cutoff or nonvisualization (ie, thrombosis or transection), and early opacification of the veins in the arterial phase (ie, arteriovenous fistula). Indirect or soft signs of vascular injury at CT include loss of clear perivascular fat planes, perivascular hematoma, or hematoma in the vascular territory.
- Active arterial bleeding at CT is characterized by extravasation of intravenous contrast material with attenuation similar to that of the adjacent iliac artery at arterial phase imaging and increases in volume at venous phase imaging. An active venous bleed is characterized by extravasation of contrast material during the venous phase that is not present during the arterial phase. Venous bleeding increases in volume and attenuation at further delayed phase imaging, if it is performed.
- Bone fragments may mimic vascular injury and simulate contrast material extravasation. Multiphasic acquisition and bone window settings help in differentiating bone fragments from an active bleed. A bone fragment remains stable in size, shape, and attenuation, unlike an arterial or venous active bleed.

are divided into three primary categories (A, stable; B, partially unstable; and C, unstable) on the basis of the integrity of the stabilizing ligaments and resultant pelvic ring instability (5), which help in determining the optimal surgical stabilization options. Each category has a subset of injury patterns based on the individual fracture components.

Young-Burgess classification of pelvic trauma is based on the direction of the force applied to the pelvic ring and the resultant injury pattern on anteroposterior (AP) pelvic radiographs (3,4). In Young-Burgess classification, pelvic fractures are divided into three primary patterns or types on the basis of the direction of the force: AP compression (APC), lateral compression (LC), and vertical shear. APC and LC fracture types are further divided into three categories with increasing severity and resultant instability (APC1–APC3 and LC1–LC3). LC injury is the most common type of pelvic ring injury and results from a force in the lateral direction that leads to fracture of the pubic rami anteriorly and fracture in the sacroiliac region posteriorly. APC injury results from a force in the AP direction and results in pubic symphyseal diastasis or pubic rami fractures anteriorly and disruption of a sacroiliac joint or iliac bone fracture posteriorly. Vertical shear injuries are the most severe type and are characterized by disruption of the anterior and posterior rings with a cephalad displacement of the affected hemipelvis. A combined or complex injury can result from a combination of any of the previously described three primary injury patterns (APC, LC, or vertical shear).

A moderate degree of intra- and interobserver agreement is seen with both of the classification systems; however, agreement improves with the expertise of the reader (6–8). Both classification systems are limited by evaluation of static images (radiographs or CT images), which do not reflect the actual displacement at the time of trauma, and hence allow underrepresentation of injury severity and pelvic instability (4). The widespread use of pelvic binders further reduces the pubic symphysis diastasis, which masks the severity of APC injuries at CT (9). Unlike the Tile system, the Young-Burgess classification system provides little guidance for treatment.

High-grade pelvic ring injury patterns with major ligamentous disruption are more likely to be associated with pelvic vascular injuries, because pelvic vessels are closely related to the injured ligamentous and bone structures (1,10,11). Vertical shear, APC3, LC3, combined, and APC2 have a higher risk of pelvic vascular injury and resultant life-threatening pelvic bleeding (12–15).

Bleeding from pelvic ring disruption is usually low-pressure bleeding (80%) from injured veins (venous) or exposed fracture surfaces (osseous). High-pressure bleeding due to arterial injury occurs in approximately 10%–20% of patients (16–19).

With improvements in CT technology and the advent of multidetector CT (scanners with 64 detector rows or more), whole-body trauma CT has been integrated into the routine evaluation of patients with multiple areas of trauma. The terms *total body CT, whole-body CT, full-body CT,* and *pan-scan* are used interchangeably, and whole-body CT is routinely performed in patients with multiple areas of trauma who are suspected

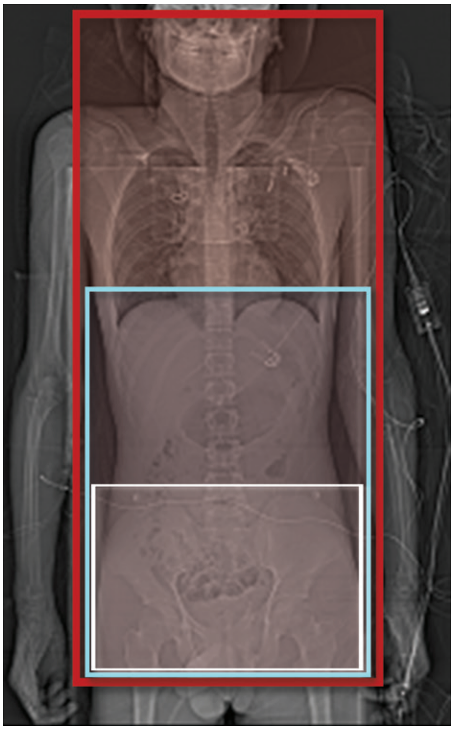


Figure 1. CT scanogram with drawing shows a whole-body CT trauma protocol: nonenhanced CT of the head (not shown), preset arterial phase acquisition from the skull base to the lesser trochanter (red box), preset venous phase acquisition from the diaphragm to the lesser trochanter (blue box), and preset delayed phase acquisition from the iliac crest to the lesser trochanter (white box).

of having internal injuries. Whole-body CT is performed rapidly and has been shown to have a significant effect on survival in patients with multiple traumatic injuries (20,21). In patients with pelvic injuries, whole-body CT is used to evaluate for nonpelvic sources of bleeding, pelvic ring injury, and the presence of pelvic hemorrhage and to help identify the potential arterial or venous source of bleeding. Multiphasic CT during the arterial and venous phases helps to differentiate an arterial from a venous source of bleeding. Differentiating arterial (high pressure) from venous (low pressure) bleeding is of paramount importance in stratification for treatment. Low-pressure venous bleeding is treated provisionally by means of external fixation, with definitive treatment performed later by means of closed reduction and internal fixation. A high-pressure arterial bleed is treated optimally with angioembolization or provisionally with pelvic packing in a hemodynamically unstable patient who is not responsive to fluid resuscitation, particularly when angioembolization service is not available (22–25). Identifying a potentially injured artery on the basis of the site of contrast material extravasation at CT, which is known as arterial mapping, requires knowledge of the anatomic course of a particular artery and the location of the pelvic hematoma (26,27). This information is of help to the interventional radiologists or trauma surgeons who are performing catheter angiography and provides them with a road map for targeted angiography and embolization.

We review the pelvic vascular anatomy as seen at CT, CT trauma protocols used to diagnose and characterize pelvic vascular injury patterns, pelvic vascular territory mapping, the spectrum of pelvic vascular injuries at CT, and the differentiation of common vascular injury patterns. We also discuss essential anatomic variants and imaging pitfalls in the assessment of pelvic vascular injury. The role of catheter angiography and angioembolization in the management of pelvic vascular injuries is summarized.

Illustrations and animations are provided to improve the understanding of the pelvic vascular injury spectrum. (The original slide presentation for this article from the RSNA Annual Meeting is available online.)

CT Technique and Protocol

CT of the pelvis is typically performed as a part of whole-body CT in a trauma patient with a clinically unstable pelvis on examination, a suspected or radiographically demonstrated pelvic ring fracture, or gross hematuria (22,28–33). Although no single standard multidetector CT protocol for diagnosis of pelvic vascular injury exists, both arterial and venous phase imaging are advocated to identify and differentiate bleeding sources, which allows further stratification for treatment. Pelvic arterial bleeding requires angiographic embolization. Venous or osseous bleeding sources generally are managed provisionally by means of external fixation, followed by definitive open or closed reduction and internal fixation of the pelvis (33,34).

Our institutions follow a whole-body CT protocol rather than selective scanning. Typically, pelvic CT angiography is integrated into whole-body CT protocols, because most patients with pelvic fractures have sustained multisystem trauma (Fig 1). CT is performed on 64–detector row or higher scanners with 0.625-mm thin collimation. One hundred milliliters of iodinated contrast material (350–370 mg of iodine per milliliter) is injected at a rate of 4–5 mL/sec followed by 30–40 mL of saline solution with a dual-head power injector. Two major approaches to whole-body CT are described: single-pass and dual-pass scans. The single pass begins with nonenhanced CT of the head followed by CT angiography from the circle of Willis through the lesser trochanters, which therefore integrates pelvic CT angiography. Dual-pass CT begins with nonenhanced spiral CT of the head, face, and cervical spine. Then a 25-second arterial phase CT scan of the pelvis is performed, followed by a venous acquisition of the entire chest, abdomen, and pelvis at 60–70 seconds. We perform volume reading at CT for acute trauma, in which an entire volume dataset is initially sent to a CT workstation attached to the CT console for an initial review. Therefore, volume reading allows the most rapid review of images and the creation of on-the-fly multiplanar reformations and three-dimensional reconstructions.

Dynamic change in the size, shape, volume, and attenuation of the contrast material helps in differentiating types of vascular injuries at CT, and it forms the basis of multiphasic CT acquisition. Delayed phase imaging (5–7 minutes) sometimes is performed after the arterial and venous phase imaging to allow differentiation of an active arterial bleed from a contained vascular injury such as a pseudoaneurysm (26). It is also performed to allow differentiation of a vascular injury from a bone fragment. Hemodynamically unstable patients with shock and hypotension may not show vascular injury during the arterial or venous phase because of a delay in the contrast material opacification of the vascular system. In these patients, an arterial bleed can be seen only during the delayed phase (35).

Delayed phase imaging typically is performed with a low radiation dose, because the primary role of this phase is to characterize the vascular lesion and not to detect it. Although some centers routinely perform delayed phase imaging, at our institution, we only perform biphasic CT examinations during the arterial and venous phases.

CT cystography usually is indicated in a patient with gross hematuria or when whole-body CT shows the presence of pelvic fractures or water-attenuation ascites (36). It is performed after arterial and venous phase imaging for assessment of the pelvic vascular injury. The reasoning for yet another CT acquisition is the risk that the contrast material spilled from a ruptured bladder could mask vascular contrast material extravasation if CT cystography is performed concurrently. Our CT cystography protocol involves diluting 20 mL of intravenous contrast material into a 500-mL bag of saline solution. The mixture is connected to the Foley catheter with intravenous extension tubing after the bladder is drained and the distal Foley catheter is clamped. The contrast material mixture (350–400 mL) is administered into the bladder under gravity for adequate distention to avoid false-negative results.

Pelvic Vascular Anatomy and Arterial Territory Mapping

Precise knowledge of the pelvic arterial anatomy and the vascular territories on axial CT images is crucial to detect vascular injuries and identify the potentially injured arteries. Understanding of the arterial course and its relationship to the bone and ligamentous structures and important CT landmarks helps the radiologist to identify the potentially injured vessels. The presence of a pelvic hematoma is the most common CT finding of pelvic vascular injuries and is seen as an ill-defined area of hyperattenuation at CT in the vicinity of the injured vessel (37). A pelvic hematoma should be differentiated from contrast material extravasation, because the presence of contrast material extravasation suggests ongoing bleeding. Clotted blood shows CT attenuation in the range of 40–70 HU (mean attenuation, 51 HU), while extravasated contrast material has higher attenuation of 85–370 HU (mean attenuation, 132 HU) (30). The location of the pelvic hematoma helps the radiologist to determine the possible injured vessel on the basis of the course of the vessel and the arterial territories (38).

Internal iliac artery branches are categorized as *(a)* parietal branches to the limb and perineum (superior gluteal, inferior gluteal, obturator, and internal pudendal branches), *(b)* visceral branches (umbilical, superior vesical, inferior vesical, middle rectal, uterine, and vaginal branches), and *(c)* somatic segmental branches (iliolumbar and lateral sacral branches) (39).

It is vital to identify four major and two minor pelvic arterial branches of the internal iliac artery on axial CT images, which can be confirmed later on multiplanar reconstruction or volume-rendered images (Fig 2) (Movie 1). The internal iliac artery has variable branching as described by Yamaki et al (40). The most common branching pattern is seen in 60%–80% of patients and includes two major branches. The inferior gluteal and internal pudendal arteries originate from a common anterior trunk of the internal iliac artery. One major superior gluteal and two minor arteries (ie, the iliolumbar and lateral sacral arteries) arise from the posterior division of the internal iliac artery. The second most common branching pattern is seen in 15%–30% of patients. In this branching pattern, the anterior division continues as the internal pudendal artery, while the posterior division of the internal iliac artery further divides into the superior and inferior gluteal arteries. The other branching patterns are uncommon and less relevant to diagnostic radiologists.

The obturator artery has a variable origin. In two-thirds of cases, it arises from the internal iliac artery. In one-third of cases it arises from the inferior epigastric artery.

All four major branches of the internal iliac arteries should be identified on axial CT angiograms. These branches have a close relationship

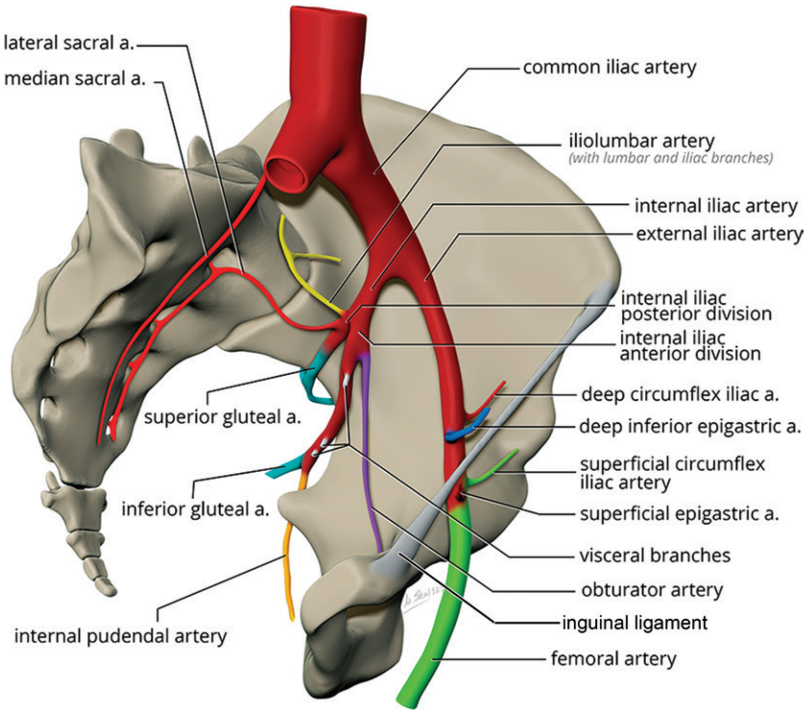


Figure 2. Illustration shows the internal iliac artery and its important branches: the lateral sacral arteries, iliolumbar artery, superior gluteal artery, inferior gluteal artery, internal pudendal artery, and obturator artery.

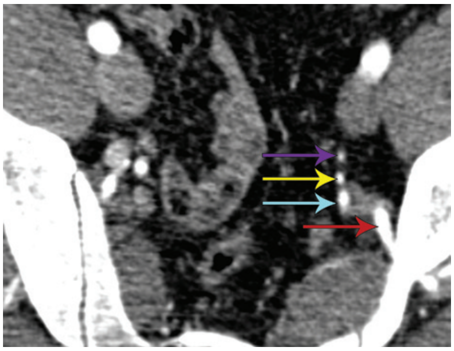


Figure 3. Axial CT angiogram at the level of the greater sciatic foramen shows localization and visualization of the four major pelvic arteries. From anterior to posterior, they are the obturator (purple arrow), internal pudendal (yellow arrow), inferior gluteal (blue arrow), and superior gluteal (red arrow) arteries.

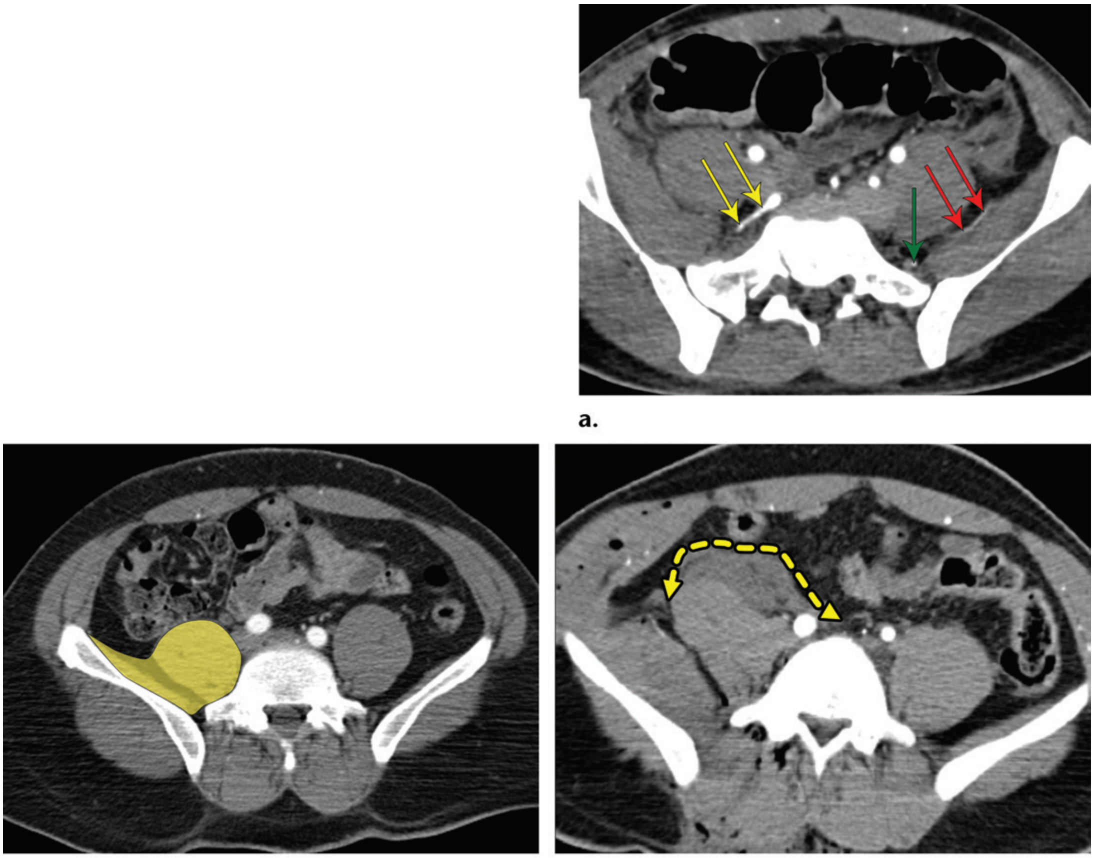
to the pelvic side wall and can be identified easily according to their caliber and location. From anterior to posterior, they are the obturator, internal pudendal, inferior gluteal, and superior gluteal arteries (Fig 3). The obturator artery is the most anterior artery and the thinnest, while the superior gluteal artery is the largest and most posterior artery.

Iliolumbar Artery

The first branch of the posterior trunk of the internal iliac artery is the iliolumbar artery. The iliolumbar artery follows a horizontal outward trajectory. On CT angiograms, it appears posterior to the psoas muscle and anterior to the superior aspect of the sacroiliac joint (Fig 4a), and it bifurcates at the level of the pelvic inlet into the iliac and lumbar branches. The iliac branch courses laterally over the iliacus muscle, supplies the iliacus muscle, and provides the major nutrient artery to the iliac crest. The lumbar branch ascends in close contact with the sacral ala, extends laterally to the L5 vertebral body, and supplies the psoas and quadratus lumborum muscles. The iliolumbar artery commonly is injured in iliac crest fractures with sacroiliac joint disruption and sacral alar fractures. The vascular territory of the iliolumbar artery (Fig 4b) and corresponding pelvic intramuscular hematoma are depicted easily in the iliopsoas muscle and along the sacral ala (Fig 4c).

Lateral and Median Sacral Arteries

The lateral sacral artery, which is the second branch of the posterior trunk, descends along the ventral sacrum laterally to the sacral foramina. On CT images, small branches can be seen entering into the sacral foramina (Fig 5a). The lateral sacral artery and the median sacral artery (a direct branch from the distal aorta) supply the sacrum, coccyx, pyriformis muscle, and the dorsal surface of the sacrum, including the erector spinae muscles and the skin. The median and lateral sacral arteries are commonly injured in fractures involving the sacrum and the transsacral foramina. The vascular territory of the lateral sacral artery includes almost the entire sacrum, with the posterior muscles and soft tissue (Fig 5b). The corresponding sacral hematoma is shown on axial pelvic CT images (Fig 5c).



a.

b.

c.

Figure 4. Iliolumbar artery in three patients. **(a)** Axial CT angiogram in a 35-year-old man shows the right iliolumbar artery (yellow arrows) arising from the posterior division of the internal iliac artery and following a horizontal outward trajectory anterior to the sacral ala. It bifurcates at the pelvic inlet level into the iliac (red arrows) and lumbar (green arrow) branches. The iliac artery is seen anterior to the iliacus muscle, and the lumbar artery runs vertically anterior to the sacral ala (left side). **(b)** Axial CT image in a 25-year-old man at the level of the L5 vertebra shows the vascular territory of the iliolumbar artery (yellow area). **(c)** Axial CT image in a 32-year-old man shows the iliolumbar artery and a corresponding pelvic intramuscular hematoma in the iliopsoas muscle (dashed line).

Superior Gluteal Artery

The superior gluteal artery is the largest branch and a direct continuation of the posterior division of the internal iliac artery. On CT images, it has a short downward anterior-to-inferior course to the sacroiliac joint, curls under the greater sciatic foramen above the pyriformis muscle, follows a superiorly concave arch-like trajectory, and terminates laterally into deep and superficial branches (Movie 2). It supplies the gluteal muscles in conjunction with the inferior gluteal artery (a branch of the anterior division).

Inferior Gluteal Artery

The inferior gluteal artery is the second largest major pelvic branch arising from the anterior trunk of the internal iliac artery. At CT, it has a downward and outward trajectory that is posterior to the internal pudendal artery. It exits the pelvis along with the internal pudendal artery through the inferior compartment of the greater sciatic foramen beneath the pyriformis muscle, above the sacrospinous ligament, and posterior to the ischial spine. Later, the vessel courses inferiorly deep in the gluteus maximus and posterior to the femoral neck (Movie 3).

The inferior gluteal artery runs in close relationship to the internal pudendal artery, and they may overlap each other before exiting the pelvis. The best way to differentiate these two arteries is to follow the outward trajectory of the inferior gluteal artery. The internal pudendal artery returns into the pelvis below the ischial spine, after making a nearly 90° turn. In addition, the caliber of the inferior gluteal artery is relatively larger than that of the internal pudendal artery, and the inferior gluteal artery runs posterior to the internal pudendal artery and remains anterior to the superior gluteal artery. The inferior gluteal artery supplies the gluteal and thigh muscles and the sciatic nerve. The vascular territory of the superior and inferior gluteal artery mainly involves the gluteal region and the greater sciatic foramen (Fig 6a). A correspond-

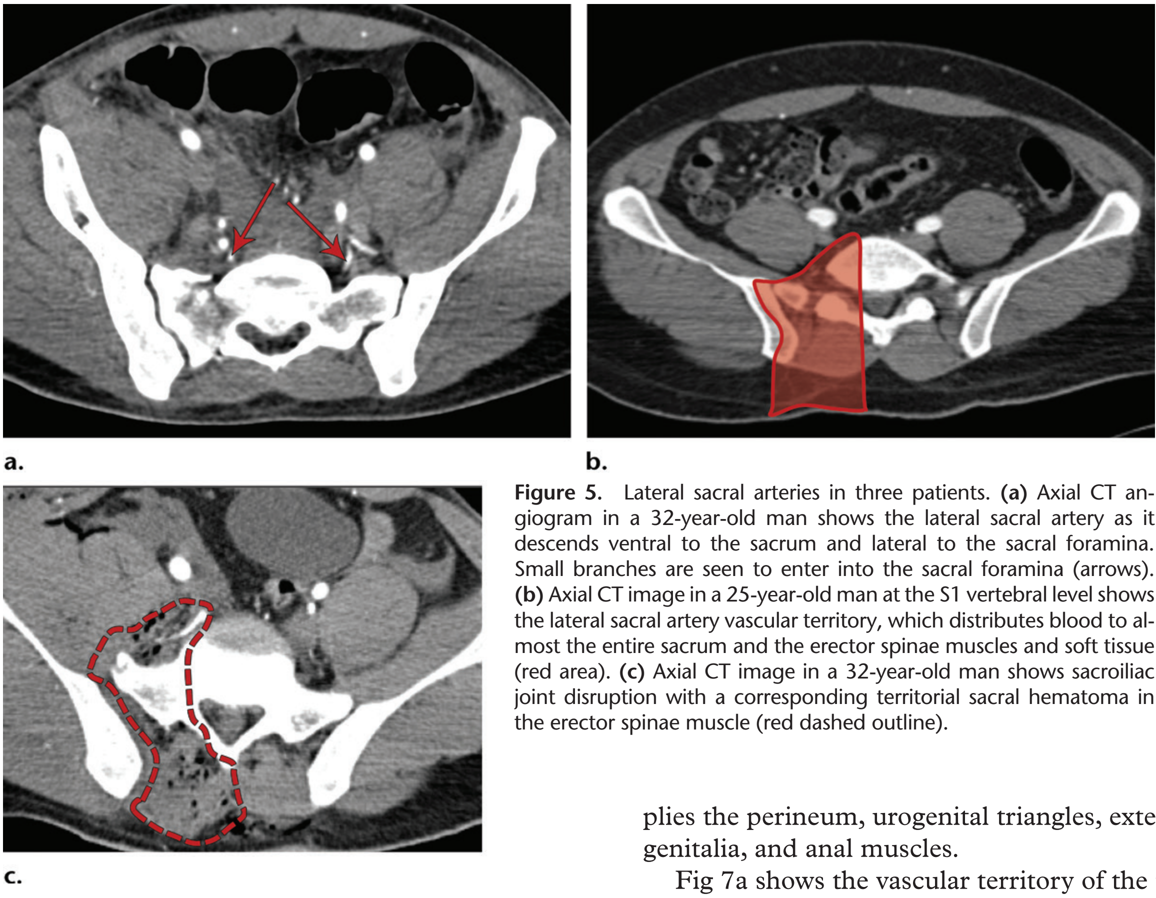


Figure 5. Lateral sacral arteries in three patients. **(a)** Axial CT angiogram in a 32-year-old man shows the lateral sacral artery as it descends ventral to the sacrum and lateral to the sacral foramina. Small branches are seen to enter into the sacral foramina (arrows). **(b)** Axial CT image in a 25-year-old man at the S1 vertebral level shows the lateral sacral artery vascular territory, which distributes blood to almost the entire sacrum and the erector spinae muscles and soft tissue (red area). **(c)** Axial CT image in a 32-year-old man shows sacroiliac joint disruption with a corresponding territorial sacral hematoma in the erector spinae muscle (red dashed outline).

ing pelvic intramuscular hematoma and contrast material extravasation in the gluteal muscles are shown in Figure 6b.

The superior and inferior gluteal arteries are prone to injury in LC fractures of iliac bone extending through the greater sciatic foramen or sacrospinous ligament avulsion fractures (Fig 6c). Inadvertent embolization of terminal branches may result in ischemia of the buttocks and sciatic nerves and sciatic nerve palsy.

Internal Pudendal Artery

The internal pudendal artery is the smaller terminal branch of the anterior trunk of the internal iliac artery. The vessel travels along the lateral pelvic sidewall in a downward and outward trajectory, remains anterior to the inferior gluteal artery, and exits the pelvis through the infrapyriformis compartment of the greater sciatic foramen, then curls back by sweeping around the sacrospinous ligament and reenters the pelvis in the ischioanal fossa, through the lesser sciatic foramen. At CT angiography, the internal pudendal artery is seen just posterior-inferior to the ischial spine and has an anteromedial trajectory in the intrapelvic course along the medial border of the obturator internus muscle and ischiopubic rami toward the pubic symphysis (Movie 4). It supplies the perineum, urogenital triangles, external genitalia, and anal muscles.

Fig 7a shows the vascular territory of the internal pudendal artery in the inferior extraperitoneal pelvic compartment, mainly along the obturator internus muscle and the ischiopubic rami up to the pubic symphysis (26). Figure 7b shows a corresponding pelvic intramuscular hematoma. Due to its long, tortuous course and close relationship to the greater sciatic foramen, ischial spine, sacrospinous ligament, acetabulum, inferior pubic rami, and pubic symphysis, the internal pudendal artery can be injured easily at multiple sites by bone fractures and ligament avulsion injuries.

Obturator Artery

The obturator artery is the thinnest branch of the internal iliac artery and commonly arises from the anterior trunk. It follows a straight downward and forward trajectory along the pelvic rim and exits the pelvis at the upper border of the obturator foramen (Movie 5). The obturator artery supplies the muscles around the hip joint. Figure 8 shows the vascular territory of the obturator artery and a related hematoma that can be seen around the hip joint, obturator foramen, and obturator internus muscle.

Inferior Epigastric and Deep Circumflex Artery

The inferior epigastric and deep circumflex iliac arteries are branches of the external iliac artery, just proximal to the inguinal ligament. Injuries

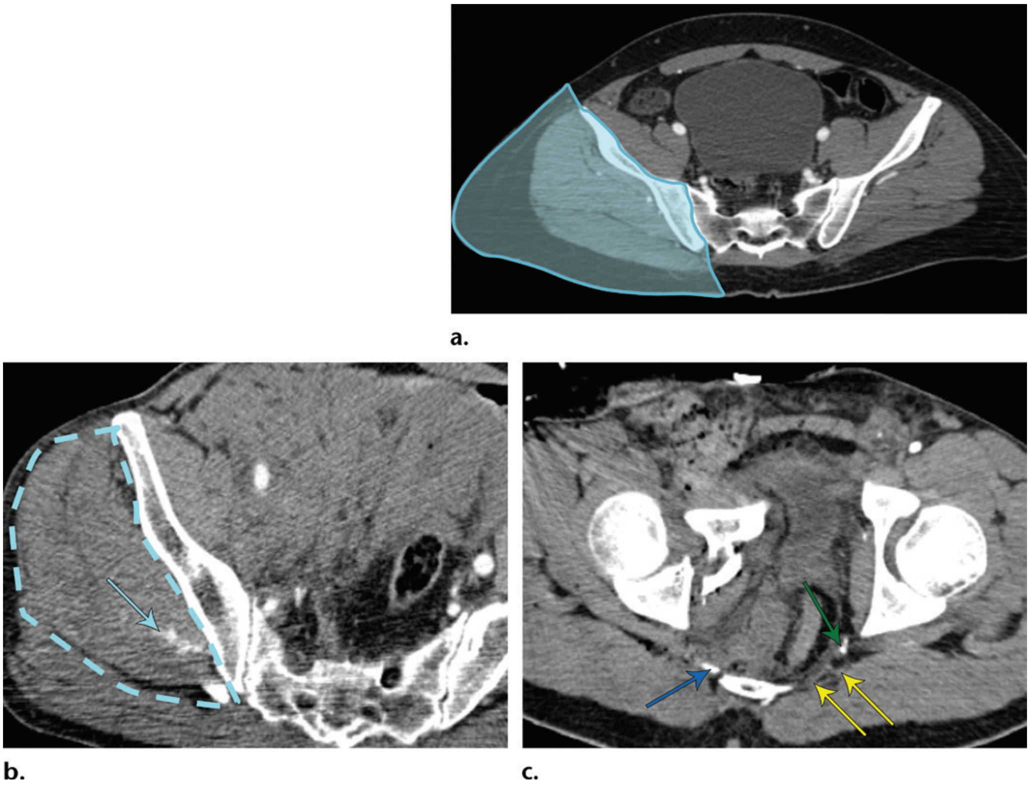


Figure 6. Superior and inferior gluteal arteries in three patients. **(a)** Axial CT image of the pelvis in a 25-year-old man shows the vascular territory of the gluteal arteries, mainly involving the gluteal muscles and greater sciatic foramen (blue area). **(b)** Axial CT image in a 35-year-old man shows an intramuscular hematoma (dashed outlined area) in the gluteal territory with active contrast material extravasation (arrow). **(c)** Axial CT image in a 35-year-old man at the level of the lesser sciatic foramen shows a right sacrospinous ligament to bone avulsion at the sacral aspect (blue arrow) and no visualization of the right inferior gluteal artery. A normal left sacrospinous ligament (yellow arrows) and a normal left inferior gluteal artery (green arrow) are shown.

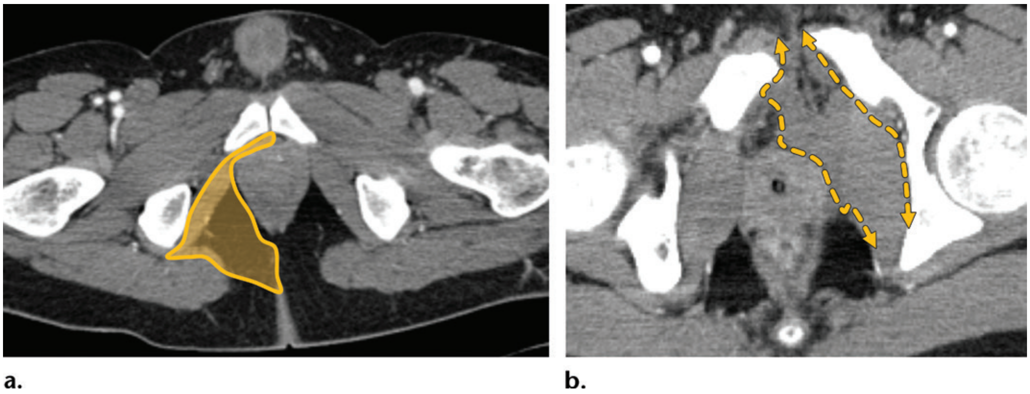


Figure 7. Internal pudendal artery in two patients. **(a)** Axial CT image in a 25-year-old man shows the internal pudendal artery vascular territory, which mainly supplies the inferior extraperitoneal pelvic compartment, along the obturator internus muscle and the ischiopubic rami up to the pubic symphysis (yellow shaded area). **(b)** Axial CT image in a 29-year-old man at the level of the pubic symphysis shows an extraperitoneal hematoma along the obturator internus and ischiopubic rami extending up to the pubic symphysis (dashed arrows).

to these arteries are uncommon and are seen in patients with injuries of the pubic symphysis and the iliac crest. The vascular territories of the deep circumflex iliac artery involve the lateral half of the anterior abdominal wall, including the lateral oblique and transverse abdominis muscles. The inferior epigastric artery supplies the rectus sheath (Figure E1) (41,42). The annotated supplementary videos (Movies 1–5) show the CT anatomy and the course of the major branches of the internal iliac arteries.

Corona Mortis

An aberrant anastomotic connection between the obturator artery and the inferior epigastric artery

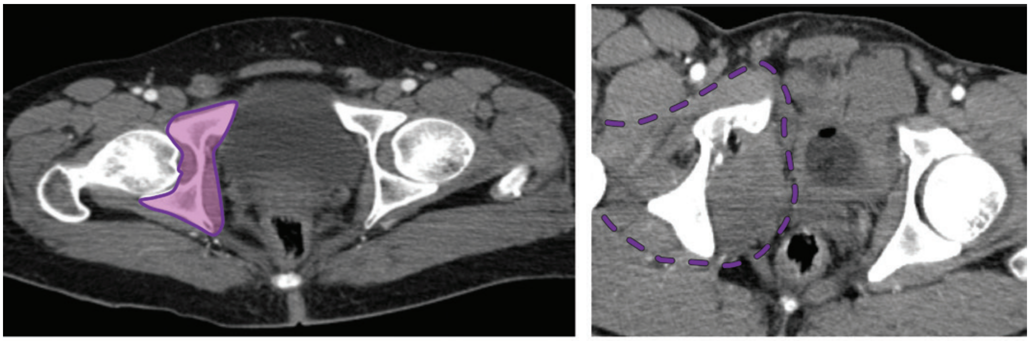


Figure 8. Obturator artery in two patients. **(a)** Axial CT image in a 25-year-old man at the level of acetabulum shows the vascular territory of the obturator artery, which supplies the muscles around the hip joint (pink shaded area). **(b)** Axial CT image in a 45-year-old man at the level of the obturator foramen shows a pelvic hematoma in the obturator internus muscle (dashed outlined area).

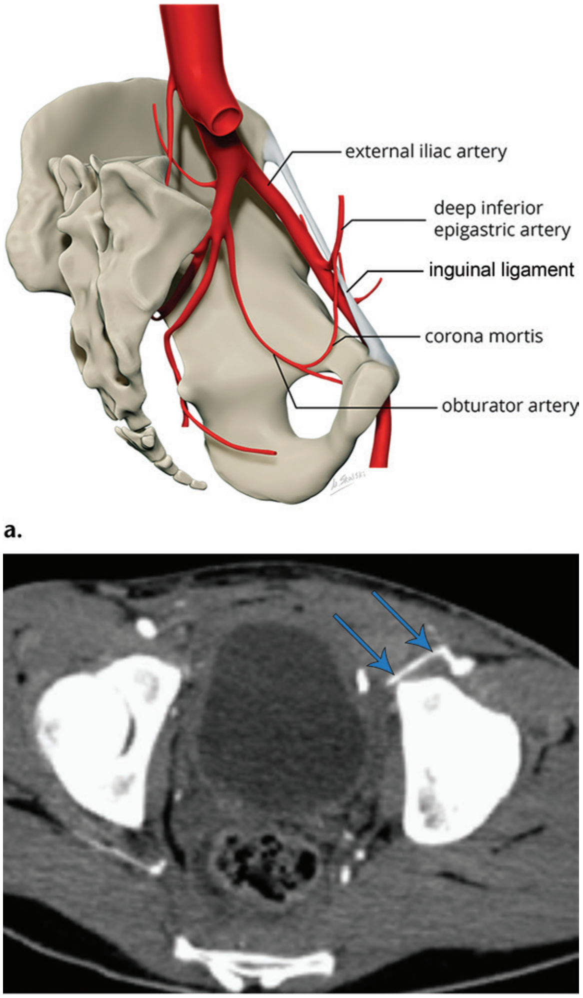


Figure 9. Corona mortis. **(a)** Illustration shows an aberrant anastomotic connection from the obturator artery to the inferior epigastric artery. **(b)** Axial maximum intensity projection CT angiogram in a 28-year-old man at the level of the acetabulum shows an aberrant obturator artery arising from the left inferior epigastric artery (a branch of the external iliac artery), which has a medial trajectory and arches anterior to the acetabulum (blue arrows).

is known as the *corona mortis* (Fig 9) (Movie 6). It is the most important anatomic variation and is present in up to 30% of patients (43–45). The corona mortis should be considered as a bleeding source if the internal iliac angiogram does not reveal a pelvic source of the bleeding at digital subtraction angiography (DSA). In such instances, angiography of the external iliac artery should be performed to exclude bleeding from the corona mortis.

Vascular injuries to the visceral branches of the male and female pelvis are also uncommon, and it is not easy to trace these arteries individually on axial CT images. Visceral branch injury is suspected if contrast material extravasation is seen away from the pelvic side wall close to the pelvic genitourinary organs at CT.

Pelvic Fractures and Vascular Injury

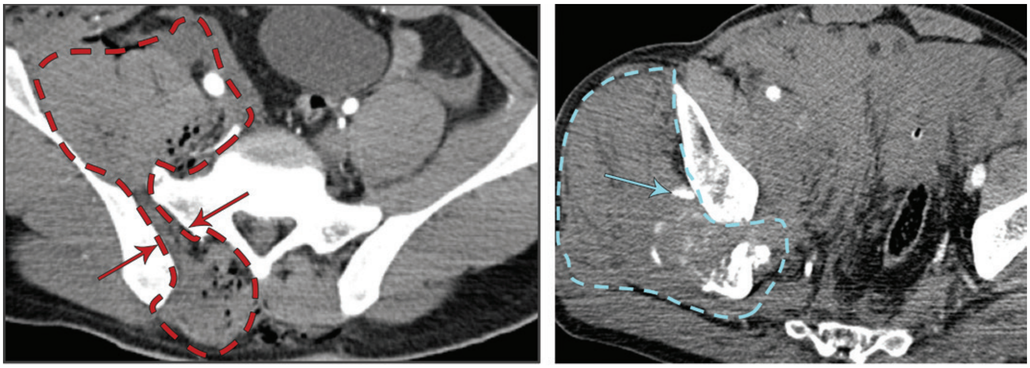
Arterial bleeding from pelvic fractures occurs more commonly from the branches of the internal iliac artery. Venous bleeding occurs from the presacral plexus and prevesical veins. The most commonly injured pelvic arteries are the internal iliac artery, superior gluteal artery, obturator artery, and internal pudendal artery (46). Table 1 shows the commonly injured major arteries of the pelvis, their vascular territories, and associated fractures.

Higher-grade pelvic fractures are associated with major ligamentous disruption, and hence are commonly associated with pelvic vascular injuries. APC3, LC3, and vertical shear combined and APC2 patterns in the Young-Burgess classification system and category C in the Tile classification system are more likely to be associated with pelvic vascular injuries and resultant pelvic hemorrhage (10,47–52). In addition to the pelvic fracture pattern, a significant correlation between vascular injuries and pelvic fracture locations was found (53).

Table 1: Commonly Injured Arteries of the Pelvis, Their Vascular Territories, and Associated Fractures

Fractures and Injured Arteries	Muscular Territories and Compartment
Posterior ring fractures*	
Iliolumbar	Psoas major and iliacus
Lateral sacral	Sacrum, erector spinae, piriformis
Median sacral	Sacrum and L5 lumbar vertebra
Superior gluteal	Gluteal muscles, piriformis
Inferior gluteal	Gluteal muscles, piriformis, posterior thigh compartment
Anterior ring fractures†	
Obturator	Obturator internus, thigh adductors compartment
Internal pudendal	Perineum
Inferior epigastric	Rectus sheath
Visceral arterial branches	Pelvic visceral organs

*Including fractures of the sacrum, sacroiliac joint disruptions, and the iliac bone.
†Including fractures of the acetabulum, superior and inferior pubic rami, and pubic symphysis.



a. b.

Figure 10. Correlation of posterior ring fractures and arterial injuries in two patients. **(a)** Axial CT image in a 32-year-old man at the level of the sacral ala shows combination injuries of the iliolumbar and lateral sacral arteries and hematomas in the right iliopsoas and erector spinae muscles (dashed outline) with sacroiliac joint disruption (arrows). **(b)** Axial CT image in a 35-year-old man shows combination injuries of the superior and inferior gluteal arteries and a pelvic gluteal intramuscular hematoma (dashed area) with active contrast material extravasation (arrow) and an LC fracture.

Posterior ring fractures injure the gluteal, iliolumbar, and sacral arteries (Fig 10). Acetabular fractures injure the obturator and inferior gluteal arteries (Fig 11). Anterior pelvic ring fractures commonly injure the internal pudendal and obturator arteries (Fig 12). Pelvic fractures through the greater sciatic notch are associated with a high rate of injury to the superior gluteal artery because of its anatomic course, which is intimately related to the bone (22,29,32). Diastasis of the pubic symphysis may indicate an increased risk of internal pudendal artery and inferior epigastric artery injury and resultant hematoma (2). Disruption of the sacrospinous ligament is associated with injuries to the inferior gluteal and internal pudendal arteries (49).

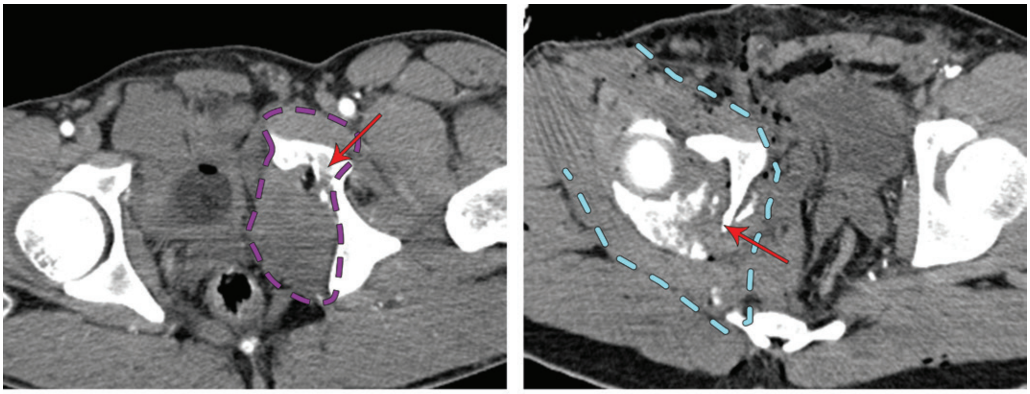
Figure 13 shows fracture sites and commonly injured vessels. Table 2 shows pelvic fracture types (Young-Burgess), the CT findings of each fracture type, the commonly injured vessels, and vascular territories. Figure E2 shows the Young-Burgess fracture types.

Spectrum of Vascular Injuries at CT

Unstable pelvic fractures are often associated with life-threatening hemorrhage. CT is routinely performed for rapid detection, localization, and characterization of the associated vascular injury. Appropriately performed CT with optimal contrast material enhancement can allow detection of the presence and extent of pelvic vascular injuries.

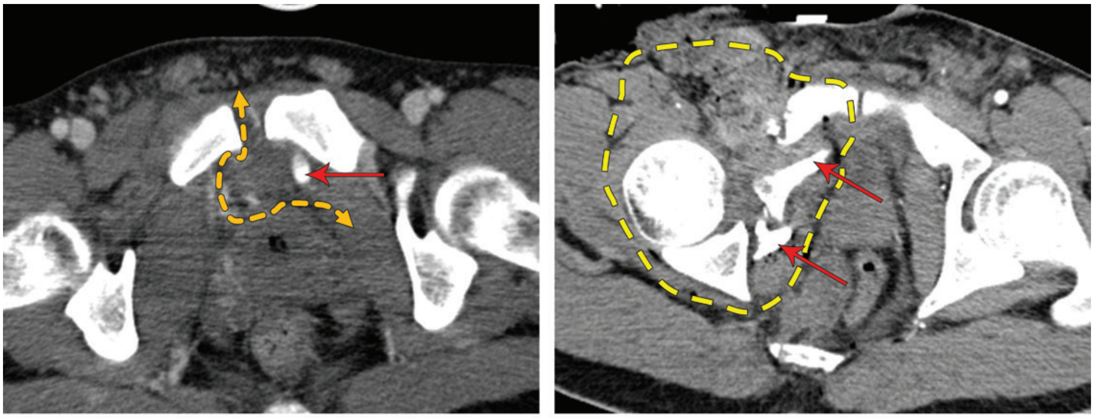
Mechanisms of Vascular Injury

Vascular injuries can result from several mechanisms of blunt trauma and include direct impact injury (crushing), shear injury (tearing),



a. b.

Figure 11. Correlation of acetabular fractures and arterial injuries in two patients. **(a)** Axial CT image in a 45-year-old man at the level of the acetabulum shows an obturator artery injury, a left acetabular fracture (red arrow), and a territorial hematoma in the obturator internus muscle (dashed outlined area). **(b)** Axial CT image in a 35-year-old man at the level of the acetabulum shows obturator and inferior gluteal arterial combination injuries, right acetabular fractures (red arrow), and territorial hematomas around the obturator internus, gluteal muscle, right hip joint, and greater sciatic foramen (dashed outlined area).



a. b.

Figure 12. Correlation of an anterior ring pelvic fracture and arterial injuries in two patients. **(a)** Axial CT angiogram at the level of the pubic symphysis shows an internal pudendal artery injury, active arterial extravasation (red arrow), and pubic symphysis injuries (dashed line). **(b)** Axial CT image in a 55-year-old man at the level of the acetabulum shows combination injuries of the obturator and internal pudendal arteries, right acetabular and ischiopubic rami fractures (arrows), and territorial hematomas around the right hip joint and the ischiorectal fossa (dashed outlined area).

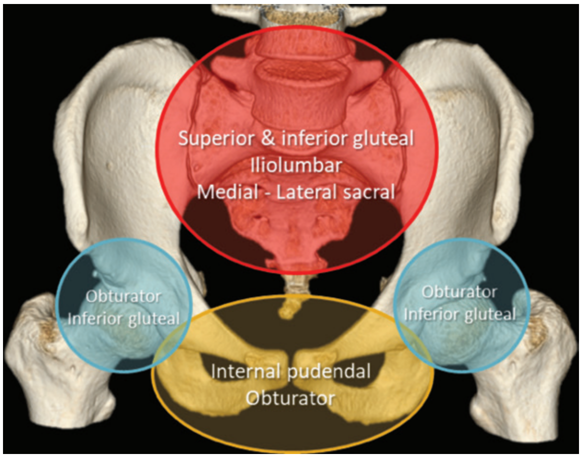


Figure 13. Pelvic ring fractures and arterial bleeding sources. The illustration shows posterior ring (red circle), acetabular (blue circles), and anterior ring (yellow oval) injuries and common associated vascular injuries.

and burst injury (35). Direct impact injury occurs when the pelvis is crushed or pinned against a fixed object at the time of a high-impact collision. Dislocations of the joint or fractures adjacent to the site of the artery may crush or tear the vessel. Rapid deceleration in motor vehicle collisions generates shearing forces, which lead to longitudinal stretching of the vessels (54). When the shearing forces exceed the elasticity of the vessel, a partial- or full-thickness injury of the vessel wall occurs. APC and vertical shear types of fractures can cause vessel stretching due to ligamentous disruption and subluxation and/or dislocation of the pubic symphysis and sacroiliac joints. Displaced fracture fragments can cause direct injury to the vessel wall.

Table 2: Pelvic Ring Injury Patterns and Vascular Injury and Pelvic Hematoma Localization

Pelvic Fracture Pattern (YB)	CT and Radiographic Signs	Vascular Territory	Hematoma Localization
APC			
1	Pubic symphysis diastasis without anterior SI diastasis	Inferior epigastric artery	Rectus abdominis
2	Pubic symphysis diastasis with anterior SI diastasis	Inferior epigastric and iliolumbar	Rectus abdominis and iliopsoas muscle
3	Pubic symphysis diastasis with anterior and posterior SI diastasis	Inferior epigastric, iliolumbar, and inferior gluteal arteries	Rectus abdominis, iliopsoas muscle, and pyriformis
LC			
1	Pubic rami fracture with sacral impaction fracture without SI ligamentous disruption	Internal pudendal artery	Perineum and urogenital triangle
2	Pubic rami fracture with posterior SI disruption and/or posterior ilium fracture	Internal pudendal artery, sacral artery, superior gluteal, and viscera branches	Perineum, urogenital triangle, erector spinae, presacral, and pyriformis
3	Lateral compression on one side and APC on the other side	Internal pudendal artery, sacral artery, superior gluteal, and contralateral inferior gluteal	Perineum, urogenital triangle, erector spinae, presacral, and bilateral pyriformis
VS	Vertical or AP displacement of SI joint alignment	Inferior epigastric, iliolumbar, and inferior gluteal arteries	Rectus abdominis, iliopsoas muscle, and pyriformis
Combined	Anterior and posterior ring fractures	Multiple arterial injuries	Multiple vascular territories

Note.— SI = sacroiliac, VS = vertical shear, YB = Young-Burgess.

Pathophysiology

Arterial injury severity varies from injury to a single layer or two layers to a complete transmural (transection) injury. An injury to one or more layers of the vessels can progress to transmural injury. The arterial injury spectrum includes intimal injury, intramural hematoma, dissection, adventiomedial or adventitial injuries, pseudoaneurysm, transection, and arteriovenous fistula (33). When hemorrhage from a partial-thickness injury is contained by the adventitia or the periarterial soft tissues, a pseudoaneurysm forms. If hemorrhage from an arterial transection decompresses into an adjacent injured vein, an arteriovenous fistula develops. Platelet aggregates form at the site of intimal injury, resulting in partial or complete thrombosis of a vessel lumen. Pelvic arterial transection can lead to fatal exsanguination.

CT Signs of Arterial Injury

Direct signs of arterial injury at CT include abrupt narrowing or contouring of an artery (eg, intimal injury, thrombosis, vasospasm, or intramural hemorrhage), intraluminal linear filling defects (ie, dissection), focal outpouching (ie, pseudoaneurysm), active contrast material extravasation (ie, transmural injury or transection), arterial cutoff or nonvisualization (ie, thrombosis or transection), and early opacification of the veins in the arterial phase (ie, arteriovenous fistula) (33,55–57). Indirect or soft signs of vascular injury at CT include loss of clear perivascular fat planes, perivascular hematoma, or hematoma in the vascular territory (35,58,59).

Bilateral comparison of the vessel size, contour, and opacification are critical to confirm and characterize vascular injury. An abrupt change in the arterial caliber at CT can be due to an arterial spasm and is seen as a concentric smooth tapered narrowing of the involved artery (Fig 14). A change in the arterial caliber also can be eccentric and irregular as a result of an intramural hematoma or extramural compression of a perivascular soft-tissue hematoma or bone fragment. A change in caliber is easier to detect and appreciate in major arteries or their larger branches. An abrupt cutoff of arterial opacification at CT is visible because of two underlying mechanisms: a transmural injury with a thrombus or a dissection with a thrombus (Fig 15a). Arterial dissection is seen as an eccentric narrowing of the involved artery, intraluminal linear filling defects, or segmental occlusion of the artery (Fig 15b). Detailed knowledge of arterial anatomy and its course, bilateral comparison, and systematic interpretation are essential to diagnose an arterial cutoff.

Active Bleed

Active pelvic hemorrhage can occur from injury to the branches of the internal iliac artery or vein, the pelvic venous plexus, or the surface of fractured bones. Accurate differentiation of active arterial bleeds from venous bleeds is vital to stratify patients for treatment, because arterial injuries are treated with transarterial angioembolization, and venous bleeding is often managed initially by means of external fixation (60).

Active arterial bleeding at CT is characterized by extravasation of intravenous contrast material, with attenuation similar to that of the adjacent iliac artery at arterial phase imaging and increases in volume at venous phase imaging (22,61) (Fig 16). An active venous bleed is characterized by extravasation of contrast material during the venous phase that is not present during the arterial phase (Fig 17). Venous bleeding increases in volume and attenuation at further delayed phase imaging, if it is performed (22,35). The blush at arterial phase imaging may suggest an active arterial bleed or a pseudoaneurysm. A pseudoaneurysm appears as a well-defined round focus of contrast material in the hematoma during the arterial phase, remains stable in size and shape (does not expand) during the venous phase, and shows washout during the delayed phase (15,33) (Fig 18). An absence of substantial enlargement in the size, shape, or volume with washout on venous or delayed phase images helps to differentiate a pseudoaneurysm from an active arterial bleed. Pseudoaneurysms are unstable vascular injuries and can progress to rupture or rebleeding. Pseudoaneurysms also may lead to partial or complete thrombosis of the involved artery, with a risk for a distal embolism (33).

Table 3 summarizes the multiphasic CT findings for the differentiation of active arterial-venous bleeding and pseudoaneurysms.

In the majority of patients, the bleeding source is venous. Arterial bleeding is present in approximately 10%–20% of patients with pelvic trauma (16); however, in patients with pelvic trauma who are hemodynamically unstable, the incidence of arterial bleeding is as high as 60% (13,38,62). Because veins are more fragile than arteries, venous bleeding usually accompanies arterial bleeding (38,62).

Prediction of the risk of bleeding in patients with pelvic trauma is multifactorial and can be challenging. The predictors include but are not limited to patient age and sex, the mechanism of injury, the injury severity score and abbreviated injury scale score, the initial blood pressure reading, the timing of external fixation, the time to angiography, and the volume and rate of blood transfusion (63,64).

CT predictors of vascular injuries, such as active contrast material extravasation, the size of the pelvic hematoma, and the laterality of the muscle enlargement, have not shown predictive ability or interobserver agreement (63). Signs of active contrast material extravasation are absent at CT in 20%–40% of patients who showed contrast material extravasation at catheter angiography, and more than half of patients with active contrast material extravasation at CT do not require embolization when DSA is performed (64). CT predictors of major vascular injuries include but are not limited to a large area of active contrast material extravasation (diameter >6 mm), the presence of a large pelvic hematoma (segmented hematoma volumes greater than 500 mL), displaced fractures of the obturator ring and greater sciatic notch (with a fracture gap of 5 mm or more), and a degree of pubic symphysis diastasis.

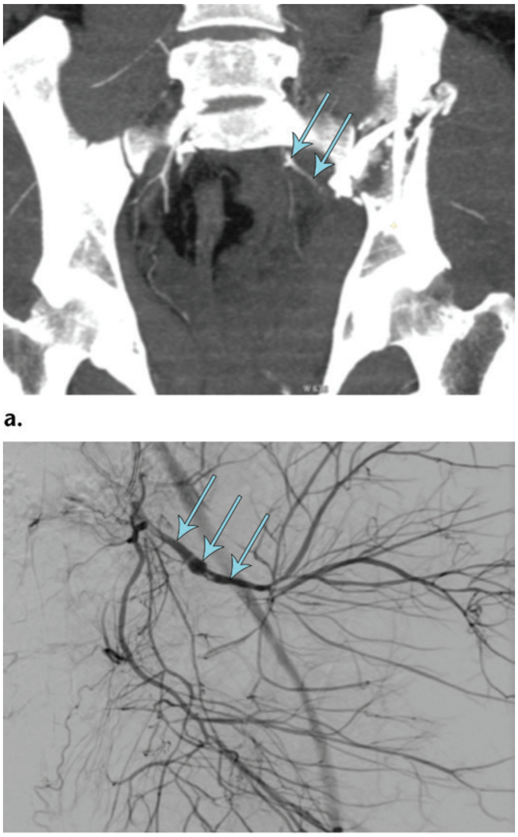


Figure 14. Arterial injury patterns: arterial wall irregularities in a 41-year-old man. **(a)** Coronal maximum intensity projection CT angiogram shows a small-caliber artery with an irregular lumen (arrows). No active arterial extravasation is shown. **(b)** Digital substraction angiogram in the same patient shows better delineation of the arterial wall irregularities. Intraluminal linear filling defects are consistent with arterial dissection (arrows).

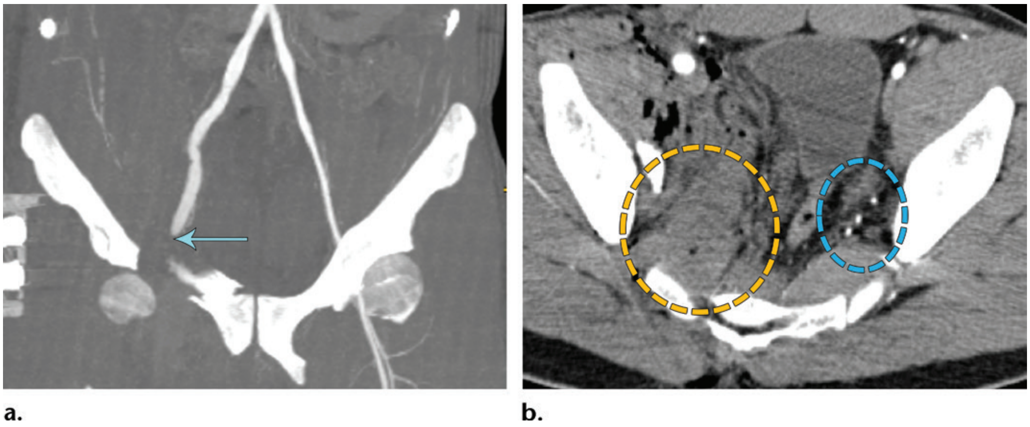


Figure 15. Arterial injury patterns: abrupt cessation of opacification in two patients. **(a)** Coronal maximum intensity projection CT angiogram in a 41-year-old man shows abrupt cessation of the opacification of the external and internal iliac arteries, which may indicate obstruction of the lumen by a thrombus or dissection or complete transection (arrow). **(b)** Axial CT angiogram at the level of the lesser sciatic foramen shows nonvisualization of arteries on the right side (yellow dashed circle). Normal arteries are shown on the left side (blue dashed oval).

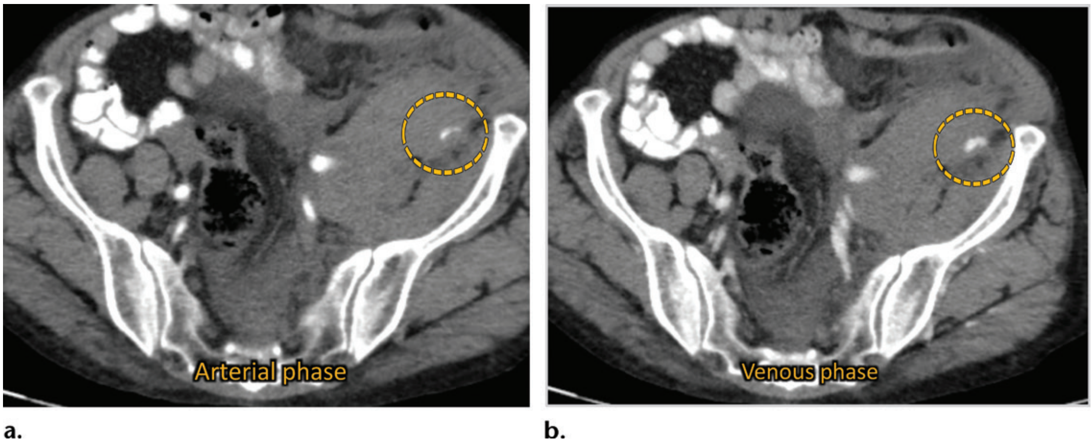


Figure 16. Arterial injury patterns: active arterial extravasation in a 40-year-old man. **(a)** Axial arterial phase CT angiogram of the pelvis shows active extravasation of contrast material (dashed circle) with attenuation at least equal to that of the iliac artery during the arterial phase. **(b)** Axial venous phase CT angiogram shows an increase in the size of the area of contrast material extravasation (dashed circle).

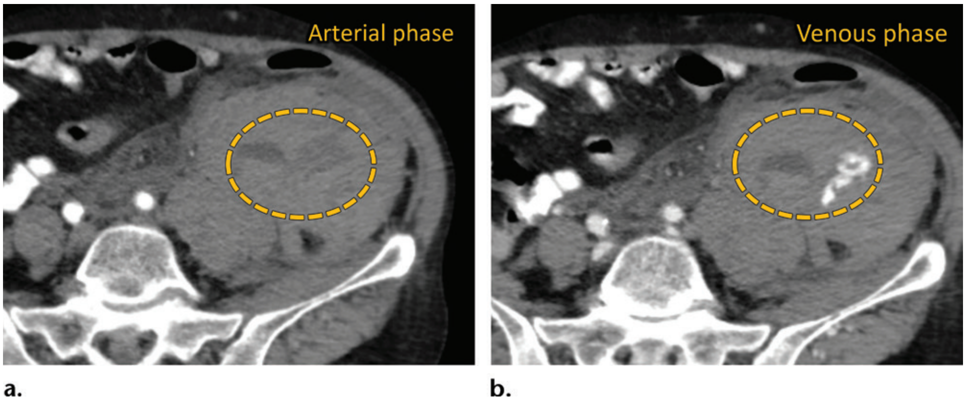


Figure 17. Arterial injury patterns: active venous bleed in a 30-year-old man. **(a)** Axial CT angiogram shows no active contrast material extravasation in the arterial phase (dashed oval). **(b)** Axial venous phase CT angiogram shows irregular intramuscular contrast extravasation (dashed oval).

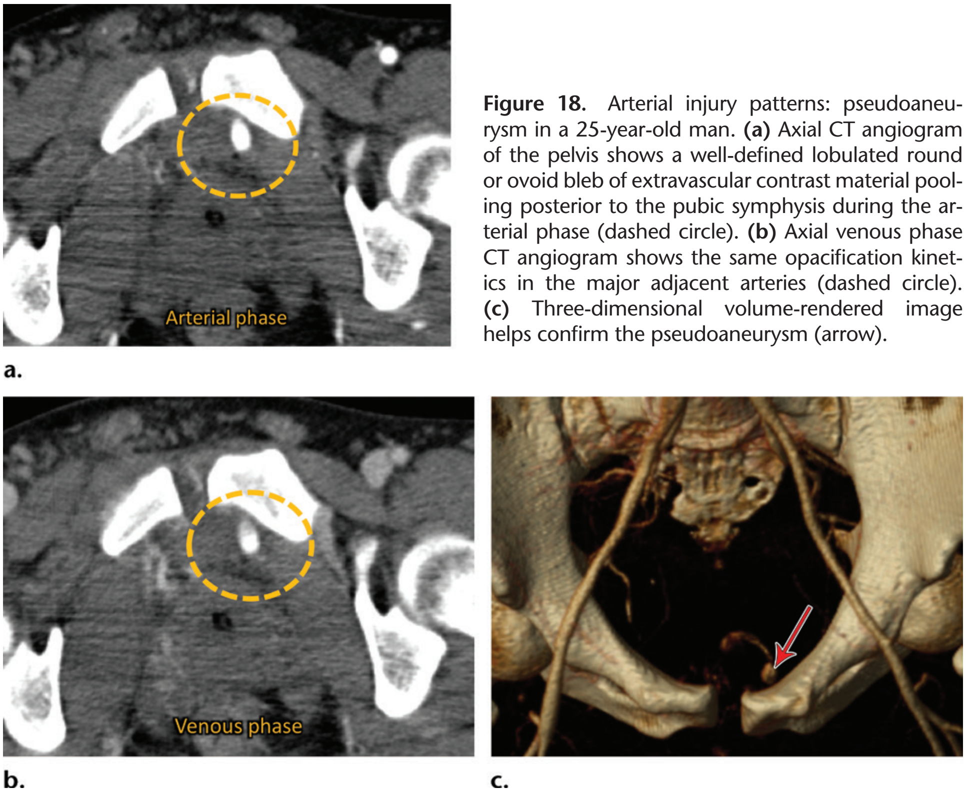


Figure 18. Arterial injury patterns: pseudoaneurysm in a 25-year-old man. **(a)** Axial CT angiogram of the pelvis shows a well-defined lobulated round or ovoid bleb of extravascular contrast material pooling posterior to the pubic symphysis during the arterial phase (dashed circle). **(b)** Axial venous phase CT angiogram shows the same opacification kinetics in the major adjacent arteries (dashed circle). **(c)** Three-dimensional volume-rendered image helps confirm the pseudoaneurysm (arrow).

Table 3: CT Differentiation of Active Arterial and Venous Bleeds and Pseudoaneurysms

Condition	Arterial Phase	Venous Phase
Active arterial bleed	Irregular contrast material collection (usually in surrounding hematoma)	Expands
Pseudoaneurysm	Well-defined contrast material collection or outpouching Smooth, round, or lobulated	Follows major arteries (slight fade)
Active venous bleed	Not seen	Irregular contrast material collection

Advanced age and atherosclerosis of the vessels are independent risk factors for vascular injury. Multiple and bilateral active contrast material extravasation further increases the risk of a major vascular injury and the need to perform transarterial angioembolization.

Pitfalls

Misdiagnosis of vascular injury at CT of the pelvis can occur because of improper techniques, patient-related factors, or artifacts (55). These pitfalls are important to recognize, because they may mimic vascular injuries or allow them to be missed. Streak artifacts arising from metallic foreign bodies, overlying leads, or hip prostheses may limit the evaluation of the pelvic vessels (65,66). Large streak artifacts may result in a nondiagnostic CT study, although substantial contrast material extravasation may still be identified. Commercially available software-based metal artifact reduction algorithms and dual-energy CT have been shown to reduce metal-induced photon starvation and metallic streaking and beam-hardening artifacts, without increasing the tube current or radiation dose to the patient (67).

Bone fragments may mimic vascular injury and simulate contrast material extravasation. Multiphasic acquisition and bone window settings help in differentiating bone fragments from an active bleed. A bone fragment remains stable in size, shape, and attenuation, unlike an arterial or venous active bleed (33) (Fig 19). Dual-energy CT technology also helps in detection of active contrast material extravasation from fracture fragments through the performance of virtual noncalcium and iodine-selective imaging (68,69).

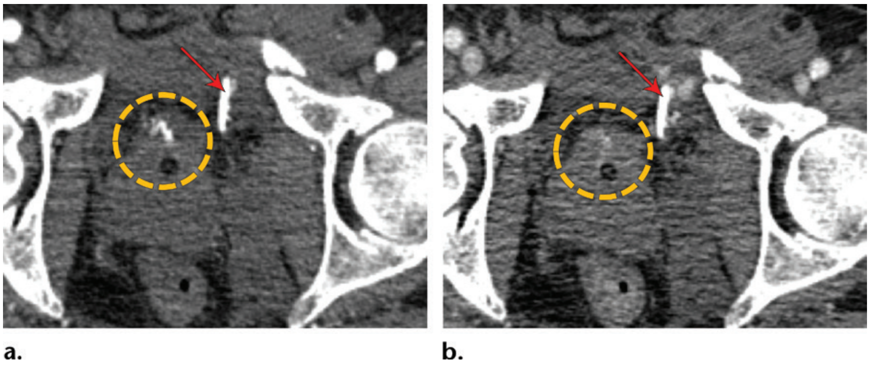


Figure 19. CT pitfall: bleed versus bone fragment in a 29-year-old man. **(a)** Axial CT angiogram shows active arterial extravasation in the internal pudendal arterial territory. A linear bone fragment (arrow) from a pubic symphysis fracture may simulate active contrast extravasation (dashed circle). **(b)** Axial CT angiogram shows the stable attenuation and shape of the bone fragment (arrow), while arterial extravasation (dashed circle) fades during the venous phase.

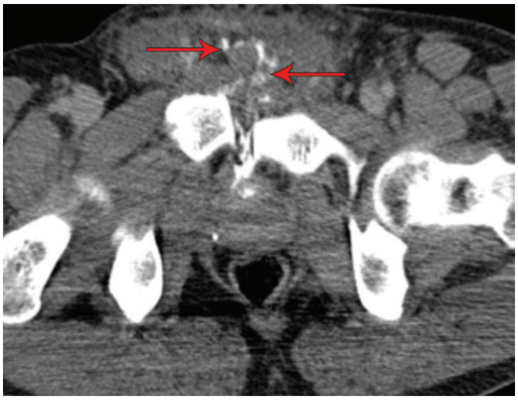


Figure 20. CT pitfall: retrograde urethrography in a 32-year-old man. Axial CT scan at the level of the pubic symphysis shows opacified urine outside the urinary bladder (arrows) after retrograde injection of contrast material through the urethral meatus. This finding can be misinterpreted as active contrast material extravasation.

Figure 21. CT pitfall: contrast material pooling in a 22-year-old man. Axial CT angiogram below the level of the inferior pubic rami shows homogeneous asymmetric contrast material pooling at the base of the penis (arrows), which may be misinterpreted as active arterial extravasation.

The presence of a pelvic binder may mask the severity of pelvic injuries, particularly APC injury patterns, by reducing the pubic symphysis diastasis (9,69). This pitfall can be avoided in a majority of patients by reviewing the other indirect CT features of an unstable pelvic ring injury, such as avulsion of the sacrospinous, sacrotuberous, and sacroiliac ligaments; fractures of the L5 transverse processes; ischial spine and inferolateral sacral fractures; sacroiliac joint distraction; and rectus abdominis muscle avulsion (9). If these imaging findings are absent or equivocal, imaging should be repeated after removal of the binder, and performance of a fluoroscopic manual pelvic stress examination with the patient under anesthesia is recommended (69).

Bladder and urethral injuries are commonly associated with pelvic fractures. Retrograde urethrography is performed to diagnose the urethral injury, and CT cystography is performed to diagnose bladder injury. Excreted urinary contrast material may obscure or mimic vascular injury when there is an active bleed. CT cystography and retrograde urethrography should be performed after multiphasic contrast-enhanced CT to avoid this pitfall (Fig 20) (70). The venous line should be flushed carefully with saline solution, rather than with the contrast material from injector tubing. Careful visualization of the renal pelvicalyceal system for excreted contrast material in bone window settings may be useful to avoid this pitfall (32,71).

A cavernosal blush in a male patient is normal and is recognized as homogeneous asymmetric contrast material pooling at the base of the penis. The blush should not be misinterpreted as active arterial extravasation (Fig 21) (72).

Slow arterial blood flow secondary to proximal major arterial injury or a hypotensive state or due to heart failure may limit the adequate opacification of the pelvic arteries at CT angiography (33). Technical optimization with automated bolus tracking or an increase in the preset delay for the multiphasic examination may be helpful in these patients.

Conventional catheter DSA should be considered when there is a high likelihood of an active bleed in a patient who is in an unstable condition or when CT is limited because of an artifact, a technique, or any of the pitfalls mentioned (55).

Pelvic Vascular Injuries at Multidetector CT and Management Implications

The management of a pelvic vascular injury is determined according to the hemodynamic status of the patient, the type and severity of the pelvic ring disruption, the presence or absence of active bleeding, the type of active bleed (arterial or venous), and the presence and volume of a pelvic hematoma at CT. DSA and angioembolization are important to the management of pelvic vascular injury. DSA and angioembolization have high technical success rates, are useful in stopping the active bleeding in patients with pelvic fractures who are in unstable condition, and improve patient outcomes (23).

In a hemodynamically unstable patient, nonpelvic bleeding sources should be identified or excluded at clinical examination, at focused abdominal sonography in trauma (FAST), or by performing whole-body CT if a patient can be stabilized by means of volume expansion or transfusions. A large hemoperitoneum on FAST or CT images in a hemodynamically unstable patient is an indication for laparotomy and hemostatic surgical intervention without delay. The absence of a hemoperitoneum and the presence of pelvic ring disruption and a large pelvic hematoma suggests a pelvic source of bleeding. DSA and angioembolization are recommended in this group of patients when an active bleed is seen on CT images (29,73–75). Signs of active contrast material extravasation are absent at CT in 20%–40% of patients who showed contrast material extravasation at catheter angiography (64). Hence DSA is considered even in the absence of an active bleed at CT if a pelvic source of the bleed is suspected (29,73,74).

In a hemodynamically stable patient with an active bleed at CT, the indications to perform DSA and angioembolization vary (33,64). A small contrast material blush is increasingly being detected at CT because of the advent of newer- generation scanners. Angioembolization in these cases is controversial and a matter of debate. More than half of patients with active contrast material extravasation at CT do not require embolization when DSA is performed (64). A few authors (15,33,76) advocate performing DSA and angioembolization, because early embolization may prevent substantial morbidity and mortality and the patient's condition may further deteriorate and result in hemodynamically instability. CT predictors of substantial vascular injuries include but are not limited to a large active area of contrast material extravasation (ie, a diameter of >6 mm), the presence of a large pelvic hematoma (ie, segmented hematoma volume >500 mL), displaced fractures of the obturator ring and the greater sciatic notch with a fracture gap of 5 mm or more, and the degree of pubic symphysis diastasis (64).

Angioembolization is also recommended in patients with a pseudoaneurysm, an arteriovenous fistula, or vessel truncation to avoid the risk of delayed bleeding (25,75). Embolization material has the potential for migration and pulmonary embolism if embolization is performed in patients with a posttraumatic arteriovenous fistula (77).

Nonselective (proximal) embolization is performed when angiography shows multiple bleeding arteries in a patient with substantial hemodynamic instability (78,79). Although nonselective embolization has higher complication rates, the benefits outweigh the risks as a lifesaving procedure (74,79,80).

There are a few critical issues to consider in performing angioembolization, especially in patients with large pelvic hematomas and without any active extravasation on CT angiograms. Selective angiography of the arterial territory should be performed, because the bleeding may be intermittent secondary to an arterial spasm or temporary tamponade caused by a hematoma. Contralateral internal iliac arterial angiography should be performed to assess any other potential source of bleeding and the possible contribution of contralateral collateral pathways to the primary bleeding source (79). If transarterial angioembolization is not available, preperitoneal packing remains a lifesaving alternative to control an arterial bleed (81).

For venous or osseous bleeding, temporary stabilization of the pelvic ring with a pelvic binder, external fixation, or a pelvic C-clamp minimizes the volume of a pelvic hematoma and allows clots to stabilize and tamponade (82).

Conclusion

The advancement of multidetector CT technology and the development of whole-body CT protocols integrating pelvic CT angiography have resulted in a quick and reliable method to diagnose major pelvic vascular injuries in patients with multiple traumatic injuries. Familiarity with the anatomy of the pelvic vessels at CT, vascular mapping, and knowledge of direct and indirect signs of vascular injury are helpful in identifying and localizing the source of bleeding. Multiphasic CT improves characterization of the vascular injury and allows differentiation of arterial from venous bleeds. Rapid detection, localization, and characterization of vascular injury at CT help to stratify the treatment of patients. Arterial hemorrhage is often managed with angioembolization, whereas most venous hemorrhages can be managed provisionally by means of external fixation or pelvic binding.

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Commentary on "Multidetector CT in Vascular Injuries Resulting from Pelvic Fractures"

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Raniga et al (1) provide a comprehensive discussion of the utility of CT for a potentially lethal and relatively common traumatic injury. Approximately 10% of patients admitted to level 1 trauma centers for blunt-force injury sustain pelvic fractures (2). The leading cause of death in the first 6 hours after pelvic fracture is abdominal and pelvic hemorrhage (3) with mortality resulting from a vicious cycle of acidosis, hypothermia, hemodilution, and trauma-induced coagulopathy (4). In-hospital mortality increases from 3%–4% to 8%–17% for the subset of patients with mechanically unstable pelvic fractures (5,6). These are more common in younger adults who have experienced high-energy trauma such as motorcycle injuries, motor vehicle collisions involving pedestrians, and falls from heights. Because of frailty, chronic comorbidities, and preexisting anticoagulant therapy, pelvic fractures in elderly patients, which typically result from low-energy mechanisms (eg, domestic falls from standing), can be equally lethal (7). After adjusting for covariates, there is a nearly eightfold increase in the mortality rate for patients with pelvic fractures who are 64 years old and older compared with those aged 15–34 years (6,8). Shock from multisystem trauma is common in both age groups (6). Mortality rates increase considerably in patients who present with shock, which occurs in 20%–50% of patients who have experienced high-energy trauma, according to Costantini et al (5).

Mortality rates in patients have declined in part because of improved resuscitation, diagnostic, and hemorrhage control interventions and damage control techniques (9). New nonimaging diagnostic modalities such as viscoelastic testing (eg, thromboelastography [TEG] and thromboelastometry [ROTEM]) provide quantitative information that allows individualized data-driven tailoring of the transfusion strategy (4). Pelvic circumferential compression devices (binders) and resuscitative endovascular balloon occlusion of the aorta (REBOA) have been adopted at high-volume trauma centers (2,10). The availability of hybrid operating rooms with angiographic and cone-beam CT capabilities is also increasing (11). Meanwhile, 64–detector row scanners, which have been commercially available since 2004, remain the CT workhorse of most trauma centers. Detector rows and dual-source technology can increase the speed of a single sweep, but the time that it takes to perform a multiphasic study is primarily dependent on contrast material kinetics and has therefore remained essentially unchanged. Improvement in image quality has been relatively incremental. Meanwhile, dual-energy CT remains uncommon or not fully utilized in the trauma setting. With the growing armamentarium of diagnostic and therapeutic options available to the trauma team, one might suspect that the role of CT has diminished, but the opposite has happened.

A recent American Association for the Surgery of Trauma (AAST) multicenter study (5) to assess the current management of pelvic fractures at high-volume level I trauma centers reported use of CT at admission in 85% of patients who presented with shock. Improvement in resuscitation techniques and the emergence of new temporizing measures that elevate systolic blood pressure (binders and REBOA) may facilitate the more liberal use of CT. This represents a major shift away from the traditional use of CT as a screening tool reserved for trauma patients who are hemodynamically stable (12).

In patients with pelvic fractures and refractory shock who are not responsive to initial volume resuscitation, focused abdominal sonography in trauma (FAST) is used in lieu of CT as a rapid bedside method to determine whether damage control laparotomy is needed for concurrent abdominal bleeding sources (13). The AAST study (5) showed that in the remaining patients with mechanically unstable pelvic fractures, approximately 60% have arterial sources of bleeding in the pelvis, a majority have polytrauma (mean injury severity score, 28.0), and a substantial number of patients have major injuries and potential sources of bleeding in other regions of the torso. For these reasons, contrast material–enhanced whole-body CT remains a critical and routine element of patient triage (whether patients undergo surgery, are sent to the angiography suite, or are treated conservatively, with transfusion). A review article on this topic is timely and apropos.

The authors primarily emphasize leveraging three major imaging features in the evaluation of pelvic fracture and related bleeding: *(a)* the pelvic fracture pattern and degree of pelvic instability, *(b)* the direct signs of vascular injury evaluated with multiphasic imaging, and *(c)* the location and size of pelvic hematomas. Taken as a whole, these features are used to predict the need for hemostatic intervention. Raniga et al (1) suggest that both angioembolization and retroperitoneal pelvic packing can be used as the first-line method to address high-pressure arterial bleeding. Most institutions favor angiography; however, some employ pelvic packing as an initial temporizing measure to avoid treatment delays associated with activation of the angiography suite. Practice patterns are largely influenced by the preferences of the surgeon and the resources available (5,14). Isolated venous bleeding is addressed with provisional stabilization with binders and external fixator devices.

In principle, the information gleaned at CT should improve patient triage by allowing rapid and objective determination of the source of bleeding. CT provides exquisite anatomic detail, and it is paradoxical that almost all other information available to the surgical team is quantitative, including vital signs, lactate levels and base deficits, and results of viscoelastic testing. However, CT assessment remains coarse and subjective. Management decisions are influenced by an overall gestalt impression because no individual CT feature is uniformly deterministic of a pelvic bleeding source. Overall, the authors provide a measured and realistic discussion of the merits and pitfalls of each CT feature. Outcome prediction in patients with bleeding pelvic fractures is inherently multifactorial and probabilistic. A familiarity with the evidence presented in this article should help the reader to render realistic recommendations.

Perhaps the most important pitfall highlighted by Raniga et al (1) relates to the diagnostic performance of contrast material extravasation. The authors note that contrast material extravasation is absent at CT when compared with catheter angiography in up to 20%–40% of instances, and that more than half of patients with contrast material extravasation at CT do not require embolization when digital subtraction angiography is performed. The statement is consistent with the highly variable accuracy metrics of contrast material extravasation reported in the literature (15). Newer-generation scanners appear to allow detection of a greater number of clinically insignificant microbleeds (15,16) and may have reduced specificity. Diameter-based threshold values that are used to differentiate between clinically inconsequential foci of contrast material extravasation from foci that require hemostatic intervention are associated with inherent information loss, leaving room for improvement. False-negative or false-positive results that lead to delayed treatment or unnecessary mobilization of limited resources and invasive procedures are bound to occur.

Despite more than a decade of experience with multiphasic CT protocols for pelvic trauma, only a handful of studies (17–20) have been performed to evaluate their accuracy in the characterization of pelvic contrast material extravasation and their efficacy for guiding management. There is a trend toward improved performance over single-phase protocols, but larger multicenter comparative effectiveness studies are necessary before we can be dogmatic on this issue. The clinical value of detecting sources of venous hemorrhage with the use of delayed phase imaging is unclear, because the prevalence of venous injury with arterial injury approaches 100% (2). If arterial bleeding can be occult at CT in 20%–40% of patients, identifying a single source of venous bleeding with dynamic information may lead to a false sense of security.

Similar ambiguity exists in considering extraperitoneal pelvic hematomas. When contrast material extravasation is present, it virtually always will coexist with a perivascular hematoma (intramuscular contrast material extravasation may be an important exception, although it is more likely to be self-limiting). In the absence of contrast material extravasation, a small hematoma is associated with a very small probability of high-pressure arterial bleeding that would benefit from hemostatic intervention, and its location is not relevant to management. Conversely, hematomas of increasingly size (even if they arise predominantly from venous sources) have increasingly high probabilities of concurrent management-altering arterial bleeding that is independent of the presence or absence of contrast material extravasation (16).

Large hematomas are typically multicompartmental, spreading along the space of Retzius, the pelvic sidewalls, and the presacral space, precluding the identification of culprit arterial territories with confidence. A sentinel clot (in the 40–70-HU range) may not be present in a patient with hemodilution and some degree of trauma-induced coagulopathy (21). So, the value of pelvic hematoma relates much more to volume than to location. But how should hematoma be measured? Diameter-based measurements are a poor estimate of volume (22). Semiautomated methods are relatively rapid but require access to and familiarity with advanced postprocessing tools (16,22). Both hematoma volume and contrast material extravasation should be quantified volumetrically (16,23), but the time effort required is prohibitive unless segmentation and measurement are automated. Recent work (24,25) has shown that pelvic hematomas and contrast material extravasation can be measured reliably with the use of deep learning computer vision methods.

Grading the severity of pelvic fractures at the point of care is also difficult. The authors describe a variety of limitations, including the modest interobserver agreement of popular grading systems and the potential masking effect of pelvic binders (26,27). "Binder-off" plain radiography is advocated by some but must be weighed against the risk of releasing tamponade and rendering sharp bone ends temporarily mobile (28). The authors point to a range of secondary signs of stabilizing ligament avulsion that can improve the accuracy and agreement of grading. These include L5 transverse process fractures (iliolumbar ligament), inferior sacral fractures (sacrospinous and sacro-ischial ligaments), and rectus abdominis insertional tears (26).

Both the Young-Burgess and Tile grading systems are widely used, and the system used in the radiology report should mirror institutional practice. Radiologists should be cognizant that the Young-Burgess system reflects several parallel grading systems based on the presumed force vector (eg, APC1–APC3 and LC1–LC3). Studies in which the utility of the Young-Burgess grading system for outcome prediction is evaluated tend to group injury types according to instability in a manner similar to the original intent of the Tile classification. For example, LC3, APC3, and vertical shear injuries may all be grouped in a vertically unstable category analogous to a Tile C injury (29). This issue is nontrivial in the clinical setting.

The authors offer additional valuable but often overlooked insights with regard to the spectrum of pelvic vascular injuries. These include *(a)* vessels with transection, thrombosis, or pseudoaneurysms under transient tamponade to result in delayed life-threatening bleeding and *(b)* the potential for nontarget embolization in patients with arteriovenous fistulae. Most scientific articles related to direct evidence of vascular injury have been focused primarily on contrast material extravasation as a predictor of angiographic evidence of bleeding (30). The discussion is clinically valuable and should stimulate further scientific inquiry. The authors provide helpful practical guidance regarding the search for vascular injuries, including using symmetry to advantage when examining vessel size, contour, and opacification. Emphasis is placed on the importance of complete knowledge of third- and fourth-order pelvic vascular anatomy. The detailed discussion of this topic is augmented with excellent images and online videos.

CT provides a large amount of information that is useful for decision making and outcome prediction in patients with bleeding pelvic fractures. However, the often complementary imaging features and patient-specific factors such as age and frailty are difficult to integrate mentally into an objective personalized estimate of risk. This is especially challenging when there are several outcomes of immediate interest—not just the need for hemostatic intervention but also the relative contribution of pelvic bleeding sources to the transfusion requirement and the risk of death.

Ideally, CT should provide quantitative information for personalized prediction of outcomes and decision-making support in the same way that continuous parameters from viscoelastic testing can be used to guide the transfusion strategy. Ultimately, computer vision tools will offer quantitative information that augment the radiologist's ability to render personalized and objective treatment recommendations (24,25). Until such time, readers should be mindful of the strengths and limitations presented in this measured and comprehensive discussion. Radiologists should have a comfort level with ambiguity and avoid rigid dogmatic thinking when encountering this complex problem.

***Disclosures of Conflicts of Interest.*—D.D.** *Activities related to the present article:* disclosed no relevant relationships. *Activities not related to the present article:* founder of TraumaVisual. *Other activities:* disclosed no relevant relationships.

D.D. supported by the RSNA Research and Education Foundation RSNA Research Scholar Grant (#RSCH1605); the National Institute of Biomedical Imaging and Bioengineering, National Institutes of Health (NIH K08 EB027141-01A13); and the Accelerated Translational Incubator Pilot (ATIP) award from the University of Maryland.

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