Pelvic Ring Fractures: What the Orthopedic Surgeon Wants to Know[1]

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Abbreviations: AP = anteroposterior, SI = sacroiliac

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SA-CME LEARNING OBJECTIVES

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

- Describe the Young and Burgess classification system.
- Discuss the key factors that contribute to pelvic stability.
- Describe the patterns of osseous and soft-tissue injuries in pelvic fractures.

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TEACHING POINTS

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Treating trauma patients with displaced pelvic fractures requires a multidisciplinary approach at a designated trauma center to reduce morbidity and mortality. Immediate recognition of pelvic ring disruption and determination of pelvic stability are critical components in the evaluation of such patients. Stability is achieved by the ability of the osseoligamentous structures of the pelvis to withstand physiologic stresses without abnormal deformation. The supporting pelvic ligaments, including the posterior and anterior sacroiliac, iliolumbar, sacrospinous, and sacrotuberous ligaments, play a crucial role in pelvic stabilization. Radiologists should be familiar with the ligamentous anatomy and biomechanics relevant to understanding pelvic ring disruptions, as well as the Young and Burgess classification system, a systematic approach for interpreting pelvic ring disruptions and assessing stability on the basis of fundamental force vectors that create predictable patterns. This system provides an algorithmic approach to interpreting images and categorizes injuries as anterioposterior (AP) compression, lateral compression, vertical shear, or combined. Opening and closing of the pelvis from rotational forces result in AP compression and lateral compression injuries, respectively, whereas vertical shear injuries result from cephalad displacement of the hemipelvis. AP and lateral compression fractures are divided into types 1, 2, and 3, with increasing degrees of severity. Knowledge of these injury patterns leads to prompt identification and diagnosis of other subtle injuries and associated complications at pelvic radiography and cross-sectional imaging, allowing the orthopedic surgeon to apply corrective forces for prompt pelvic stabilization. *Online supplemental material is available for this article.*

Introduction

In young patients, displaced pelvic ring fractures result from the transfer of substantial kinetic energy to the body. They most commonly result from trauma, such as motor vehicle accidents (60% of cases), falls from a height (30% of cases), and crush injuries (10% of cases) (1). Thus, displaced pelvic ring injuries are a marker for high-energy trauma and are often associated with other life-threatening injuries. Although the mortality rate in patients with pelvic fracture has declined in recent years, the incidence of pelvic fractures is increasing because of the increased incidence of high-speed motor vehicle accidents and increased survival rates after these accidents (2). Pelvic fractures increase the risk for mortality primarily because of hemorrhage caused by direct injury to adjacent vasculature (venous and arterial) from osseous fragments, disruption of vessels by shear forces, and osseous bleeding (3). After a displaced pelvic fracture, mortality is most often related to acute hemorrhage in patterns that increase the pelvic volume, such as anteroposterior (AP) compression

and vertical shear, but it may also result from associated injuries in patterns such as lateral compression, which reduces the pelvic volume (4–7). An external fixator or pelvic binder may stabilize the pelvis and tamponade venous hemorrhage but is often ineffective for hemodynamically significant arterial bleeding. Patients with hemodynamically significant arterial bleeding require either embolization or intrapelvic packing (8). Other associated serious injuries include urogenital, lumbosacral plexus, and concomitant long bone fractures (5,9). A systematic approach with rapid and accurate identification of injuries and prompt intervention is critical in the initial treatment of patients with pelvic fractures (10,11).

In elderly patients, nondisplaced or minimally displaced pelvic ring injuries may also result from low-energy trauma or falls and are distinct from displaced fractures secondary to high-energy trauma. Typically, these injuries are not life threatening and often heal without intervention. In this article, we discuss the anatomy and biomechanics of pelvic ring disruptions with the use of pattern recognition and force vector insights based on the Young and Burgess system, which is intuitively illustrated with three-dimensional modeling and animation, with case examples and a brief discussion of treatment options.

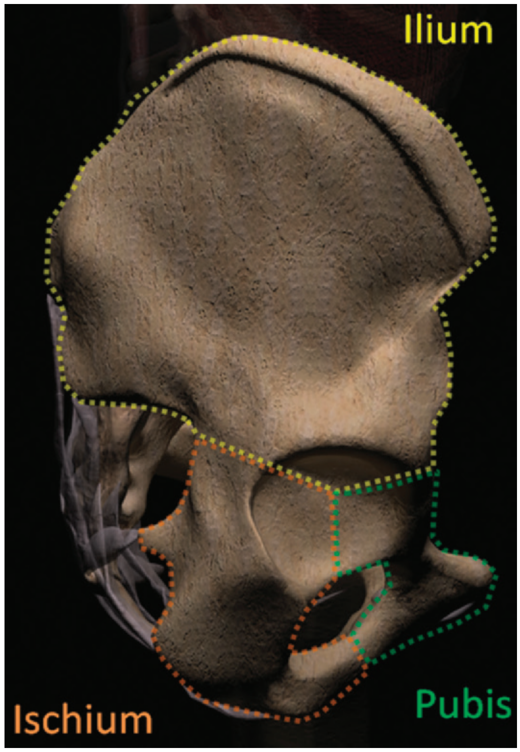

Figure 1. Computer-generated lateral view of the pelvis shows the three components of each of the paired innominate bones: ilium (yellow), ischium (orange), and pubis (green). The borders between the three bones are determined by the location of the immature physeal triradiate cartilage, which is fully fused by adulthood.

Relevant Anatomy and Biomechanics of the Pelvis

Knowledge of the anatomic and biomechanical contributions of the bone and ligamentous pelvic structures is important to understand the mechanisms of pelvic injury, the role these structures play in pelvic stability, and their influence on the diagnosis and management of pelvic injury. The pelvis is a complex ringlike structure composed of three principal bones: the paired innominate bones and the sacrum (Movie 1). The innominate bones are joined anteriorly at the pubic symphysis, and the sacrum is joined to the innominate bones at the sacroiliac (SI) joint (12). Each innominate bone is formed by the fusion of embryonic ilium, ischium, and pubis at the triradiate cartilage (Fig 1) (2). The pelvic ring consists of two arches: the posterior arch, a stronger arch that extends behind the acetabular surfaces and includes the sacrum, SI joints, and posterior ilium, and the anterior arch, a weaker arch made of the pubic rami bones and symphysis (Fig 2).

Stability is achieved through the ability of the osseoligamentous structures of the pelvis to withstand physiologic stresses without abnormal deformation (13). The interosseous SI ligaments are the strongest ligaments and may be further subdivided into thin anterior and thick posterior fibers. The anterior SI ligaments resist external rotation of the ilium relative to the sacrum, whereas the stronger posterior ligaments resist both internal rotation and vertical displacement. The sacrospinous ligament extends inferolaterally from the posterior sacrum and attaches to the ischial spine. It is just posterior and inferior to the SI joint and provides rotational stability. The sacrotuberous ligament is superficial to the sacrospinous ligament and extends vertically from the posterolateral sacrum to the ischial tuberosity. It resists vertical shear and flexion forces. The iliolumbar ligaments extend from the posterior iliac crest to the transverse processes of L4 or L5 and secure the pelvis to the lumbar spine (10,12,13).

Teaching Point

The posterior SI ligament is a key vertical stabilizer, maintaining the sacrum in its normal position in the pelvic ring (14). The posterior pelvis and sacrum are the keystone elements of the pelvis because they provide structural support and stabilization of the entire pelvic ring. Stabilizing structures of the posterior pelvic ring may be compared with the functional structure of a suspension bridge, with the strong posterior ligaments maintaining tension at the posterior margin of the SI joint and suspending the posterior superior iliac spines to maintain an open

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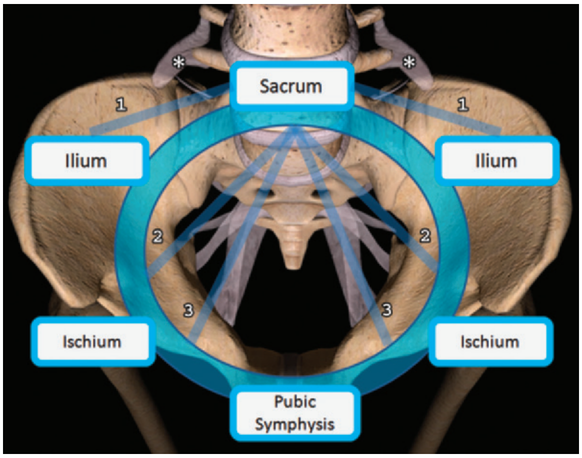


Figure 2. Computer-generated image shows the stabilizing structures of the pelvic ring. The bony pelvic ring (blue circle) is made up of the sacrum and bilateral innominate bones and stabilized by the SI *(1)*, sacrospinous *(2)*, and sacrotuberous *(3)* ligaments. Secondary stabilization is provided by the iliolumbar ligaments (∗). Clinical instability is most severe in patients with injury to the posterior ring structures.

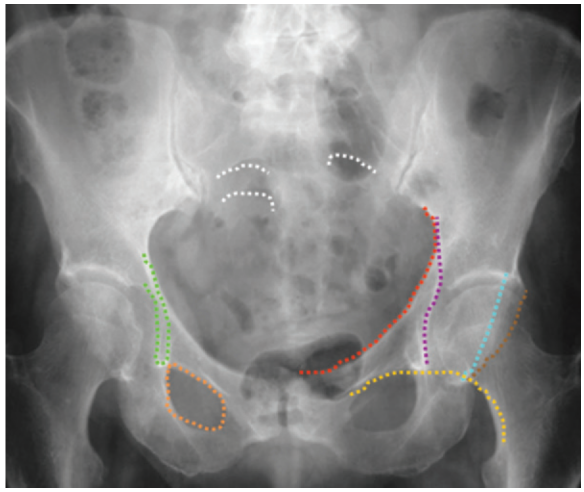


Figure 4. AP radiograph shows the key contour lines for evaluating the pelvis: iliopectineal (red), ilioischial (purple), anterior rim (blue), posterior rim (brown), Shenton (yellow), teardrop (green), obturator (orange), and sacral arcs (white). AP radiographs are helpful for assessing pelvic symmetry and anterior ring, iliac wing, and transverse process fractures.

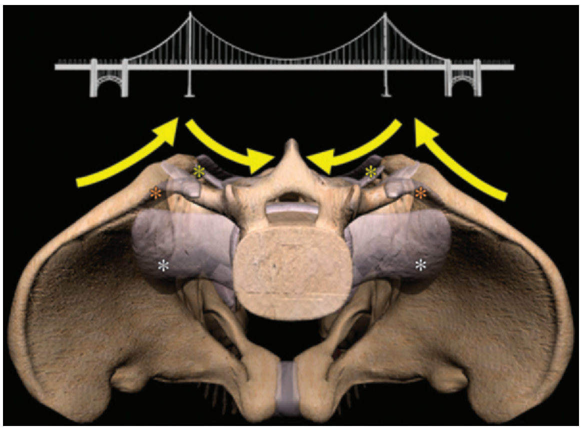


Figure 3. Computer-generated image shows the stabilizing structures of the posterior pelvic ring, which may be compared with the functional structure of a suspension bridge, with the strong posterior ligaments maintaining tension (yellow arrows) at the posterior margin of the SI joint and "suspending" the posterior superior iliac spines to maintain an open pelvic configuration. Orange ∗ = iliolumbar ligaments connecting to the L5 transverse processes, white ∗ = anterior SI ligaments, yellow ∗ = posterior SI ligaments.

Teaching Point

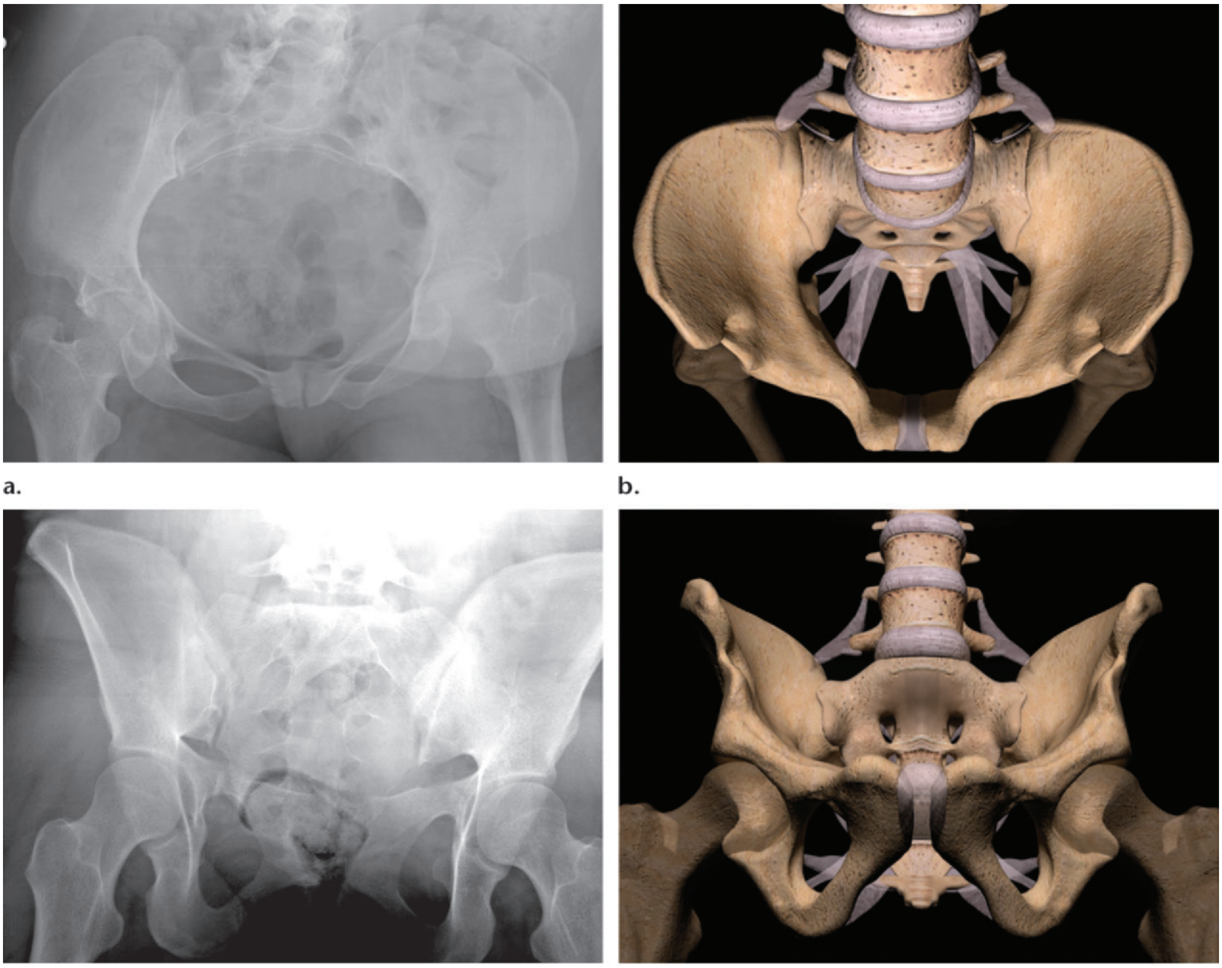
pelvic configuration (Fig 3). The pubic symphysis is stabilized by a series of ligaments and primarily serves as a strut to improve anterior ring stability during ambulation. However, the pubic symphysis is the weakest link in the pelvic ring, contributing only 15% of intrinsic pelvic stability (5,11).

Imaging Evaluation

The osseous and ligamentous components of the pelvis cause it to biomechanically function as a ring, and disruption of one portion of the pelvic ring must raise suspicion for disruption in a second location. Further, the complex anatomy of the pelvis and its often subtle imaging findings may be challenging to the radiologist. Thus, it is critical to adhere to a systematic and rigorous approach in evaluating pelvic images.

Initial radiographic evaluation of the pelvic ring consists of a standard AP view as part of the initial trauma series (Fig 4). Anterior ring fractures are most often evident on AP radiographs. Posterior ring injuries, such as sacral fractures, are often occult and require careful scrutiny of the sacral arcs and, often, further imaging (15).

Additional radiographic views that may be helpful and may usually be acquired without moving the patient include pelvic outlet (Ferguson) and inlet views. The pelvic outlet view is an AP view obtained with the x-ray tube angled 25°–45° cephalad. It best depicts the SI joints, vertical fractures of the sacrum, extension of fractures into the neural foramina, and cranial or caudad displacement of fracture fragments. The pelvic inlet view is an AP view obtained with 30°–60° caudad tube angulation that allows evaluation of the sacral arcuate lines, AP displacement or internal rotation of fracture fragments, and alignment of the pubic symphysis (Fig 5) (16–18). Judet views are obtained to better depict associated acetabular fractures and are often requested by orthopedic surgeons because they are easily reproducible in the operating room for surgical planning. Computed tomography (CT) has become a routine part of pelvic imaging because it



a. b. c. d.

Figure 5. **(a, b)** Inlet radiograph **(a)** and corresponding computer-generated image **(b)**, obtained with the beam oriented 30°–60° caudally through the pelvis and the patient lying supine, show the pelvis. These images help detect anterior or posterior displacement of bony pelvis structures, rotational deformities, sacral arch fractures, and sacral crush injuries. **(c, d)** Outlet radiograph (Ferguson view) **(c)** and corresponding computer-generated image **(d)**, obtained with the beam oriented 25°–45° cephalad and perpendicular to the sacrum, show the pelvis. These images help detect sacral fractures, SI joint widening, and hemipelvis elevation.

provides better depiction and characterization of radiographically occult posterior ring fractures. Magnetic resonance (MR) imaging is rarely indicated in patients with acute pelvic trauma, but studies have shown its value in depicting acute pelvic ring disruptions and providing additional information on ligamentous injury (19). However, its limited availability and longer acquisition times make it impractical in the acute setting.

Radiologic evaluation of pelvic injuries should begin with the acquisition of a bedside AP radiograph during the initial medical evaluation to enable the radiologist to identify characteristic injury patterns, which indicate potential mechanical stability. Any additional imaging must be closely coordinated with the clinical team and take into account the patient's hemodynamic status to determine whether additional radiographic views, pelvic CT, or angiography is necessary (Fig 6).

Pelvic Ring Injuries

When sufficient force is applied to the pelvic ring, it will deform through either a fracture of the innominate bones or sacrum or through a disruption or dislocation of the pubis or SI joints. Because the pelvis is a ringlike structure, significant disruption and displacement in one area must be accompanied by a second disruption in another area. Thus, most pelvic ring injuries include fractures or dislocations of both the anterior and posterior structures (11).

When assessing pelvic ring injuries, it is often helpful to think in terms of the effect on pelvic stability. Pelvic stability depends on the integrity of a combination of bones and ligaments. Stable fractures are able to withstand normal physiologic loading without significant displacement over time, whereas unstable fractures tend to displace (20). In general, fractures and dislocations

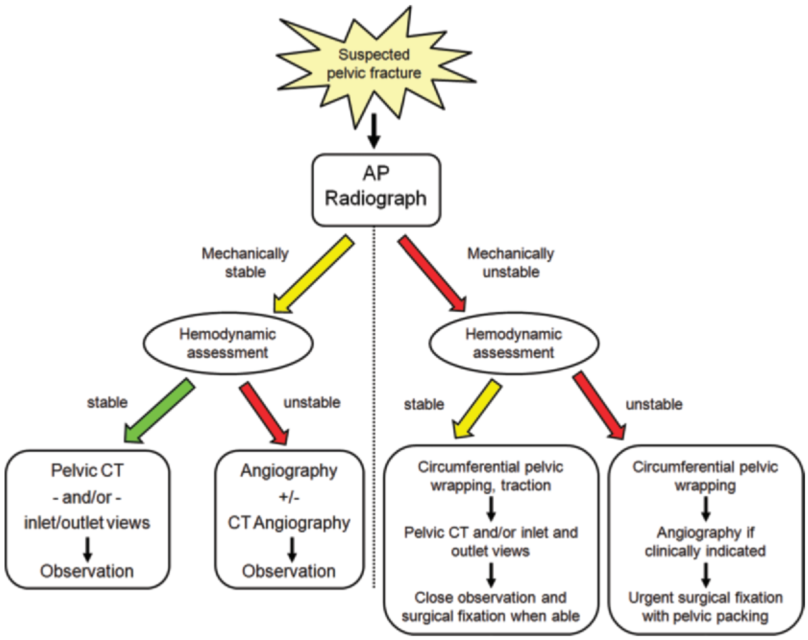


Figure 6. Chart shows the radiologic evaluation and initial treatment of patients with a suspected pelvic fracture.

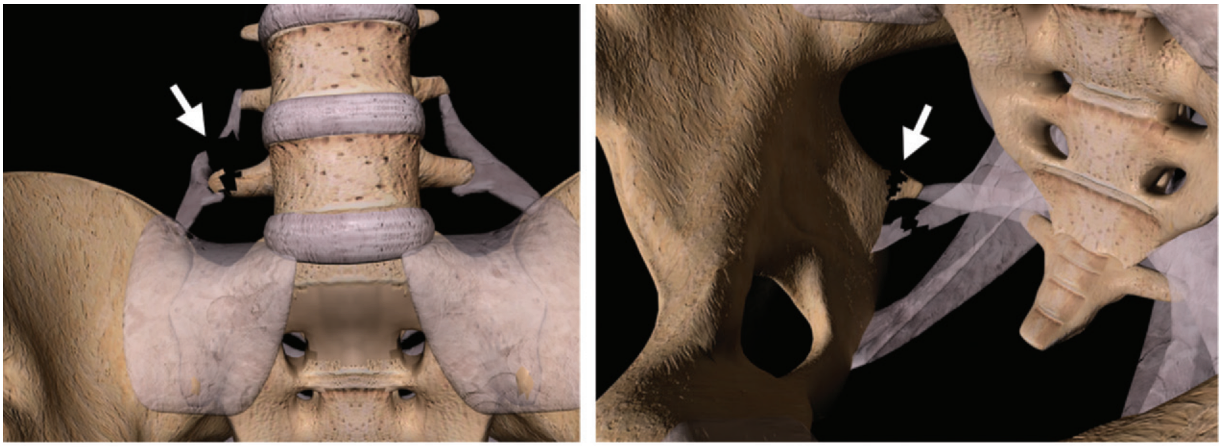
with displacement of more than 1 cm and injuries that compromise the posterior SI ligaments are often unstable and warrant close attention at initial evaluation.

Pelvic injuries may be identified by two dominant patterns of displacement: opening and closing of the pelvis, a result of rotational forces, and cephalad displacement, a result of vertical forces transmitted to the pelvis by axial loading from the lower extremities (21). The injuries with anterior displacement and an intact posterior ligamentous complex are referred to as being rotationally unstable because the hemipelvis is able to rotate into either internal or external rotation around the intact posterior ligamentous structures. However, vertical displacement is resisted. Pelvic ring fractures or dislocations that include significant posterior displacement or disruption of the posterior SI ligaments are much more unstable. In these injuries, the hemipelvis and limb are completely disconnected from the axial skeleton, and the hemipelvis is free to rotate internally or externally and to migrate proximally. These injuries are referred to as being globally or vertically unstable and are associated with neurovascular injury and a higher rate of further displacement if left untreated. Other secondary signs of instability are avulsion fractures of the sacrospinous or iliolumbar ligaments and L5 transverse process avulsion fractures, which indicate that the pelvis was more significantly displaced at the time of injury (Fig 7). In the literature, pelvic ring injuries are commonly grouped as entities that are distinct from acetabular fractures, with combined injuries usually seen in patients with severe trauma (22). A discussion of acetabular injury is beyond the scope of this article. In the setting of pelvic ring disruption, the presence of an acetabular fracture indicates severe trauma and, more often, a lateral compression injury, with force applied over the great trochanter (13).

Teaching Point

Classification of Pelvic Fractures

The purpose of classifying pelvic fractures is to provide a common language that facilitates communication between the specialists caring for the patient and a means for relating clinical findings to treatment and prognosis (5). To define a specific patient's injury, Letournel and Judet (13) proposed an anatomic classification on the basis of the site of injury that includes injuries to the posterior ring, acetabulum, and anterior ring. Pennal et al (21) initially introduced a classification system on the basis of the force and direction of the injury. Subsequently, Tile (23) elaborated on this system, using an alphanumeric system on the basis of pelvic stability to determine the prognosis and treatment options. If a pelvic fracture is stable, it is type A. If a fracture is unstable to rotation but vertically stable, it is type B. A severe pelvic ring disruption that is unstable to both rotation and vertical displacement is type C. Each fracture type has multiple subcategories on the basis of the individual component fractures (10). The distinction between stable and unstable injuries is important, because patients with unstable fractures require surgical correction and have a higher incidence of associated injuries. Burgess et al (24) modified Pennal's initial mechanistic classification by quantifying the forces applied to the pelvic ring and adding a new category for combined mechanical injuries to incorporate conditions that resulted



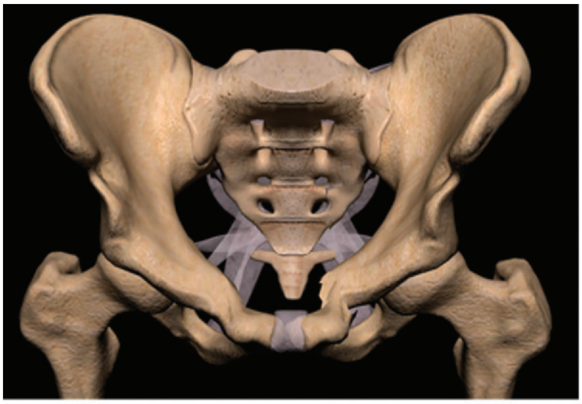
a. b.

Figure 7. Correlation of the radiographic signs of pelvic instability. **(a)** Computer-generated image shows avulsion injuries (arrow) of the ischiolumbar ligament attachment at L5. **(b)** Computer-generated image shows avulsion injuries of the distal attachment of the sacrospinous ligaments (arrow).

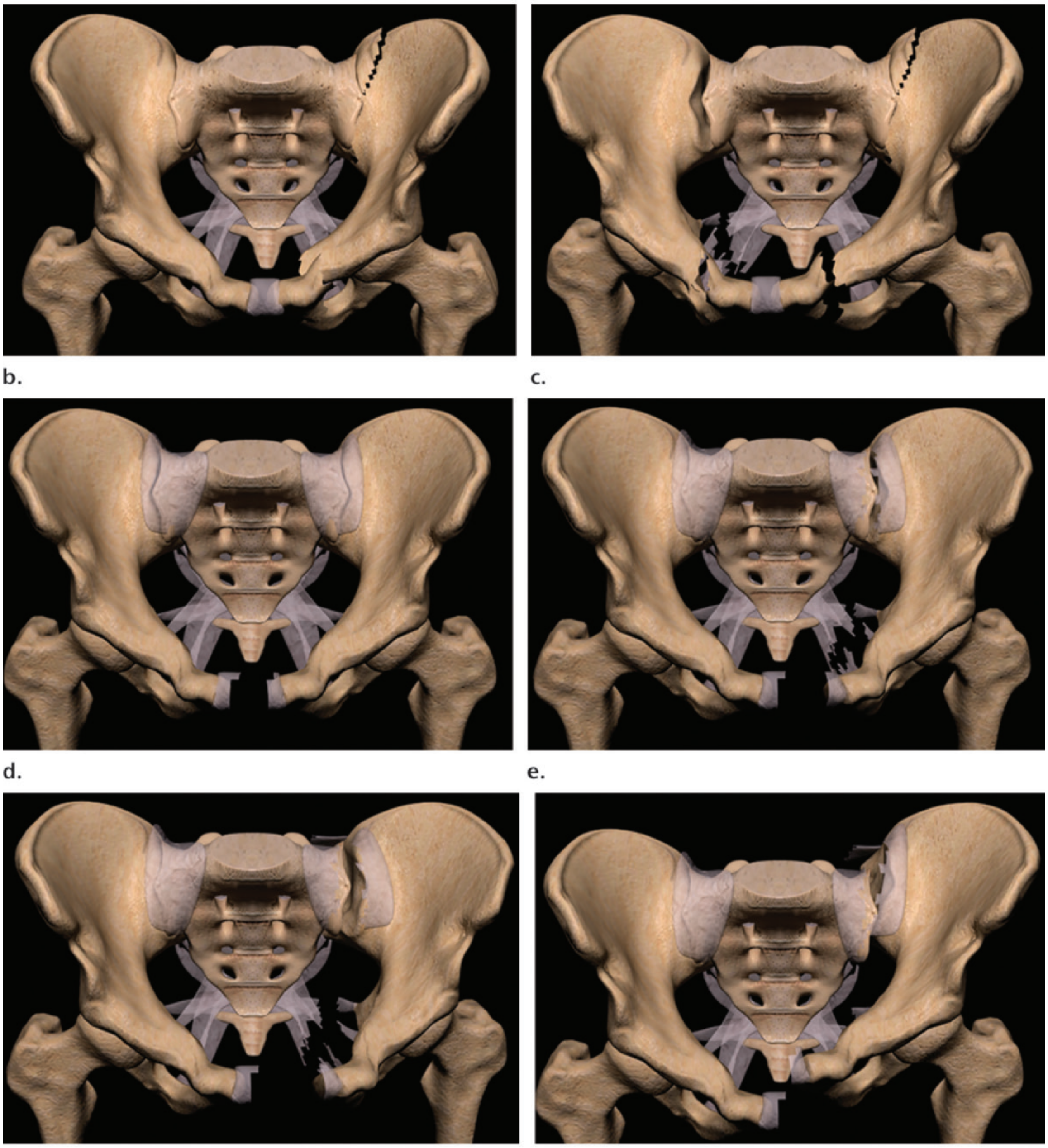
Key Characteristics of the Young and Burgess Classification of Pelvic Ring Injury

Type of Injury	Figure	Morphologic Characteristics	Stability
Lateral compression	...	Transverse overlapping obturator ring fractures	Head injury; direct vascular, neural, and bladder injuries
1	8a	Sacral impaction (buckle), intact ligaments	Stable
2	8b	Iliac crescent fracture	Rotationally unstable, vertically stable
3	8c	Lateral compression type 1 or 2 on one side and AP compression injury on the opposite side	Globally unstable
AP compression		Diastasis of pubic symphysis without anterior fracture	Substantial hemorrhage
1	8d	Less than 2.5 cm pubic diastasis	Stable
2	8e	More than 2.5 cm pubic diastasis, widening of anterior SI joint	Rotationally unstable, vertically stable
3	8f	Often more than 5 cm pubic diastasis, widening of both anterior and posterior SI joints	Globally unstable
Vertical shear	8g	Vertical displacement of hemipelvis, fractures of pubis and SI joint	Visceral injuries, unstable
Combined	...	Complex fracture with combined elements of AP compression, lateral compression, or vertical shear	Variable

from a combination of forces and directions (25). The Young and Burgess classification is primarily based on the mechanism of injury and is currently the most widely used system reported in the orthopedic literature (26). Because it is based on force vectors, it provides the information needed to apply corrective forces to realign normal pelvic anatomic relationships. This information became essential with the advent of external fixation, which offers the benefit of rapid pelvic stabilization despite severe injury. The Young and Burgess system provides an algorithmic approach to pelvic radiography, with the pattern of anterior arch injury indicating the type of posterior injury. The system of pattern recognition enables depiction of subtle posterior fractures and provides a predictive index for both local and distal associated injuries (24,27). The types of fracture in this classification system are based on the predominant direction of the force vector at the time of injury and include lateral compression (50%–70% of cases), AP compression (20%–30% of cases), vertical shear (14% of cases), and combined mechanism (Fig 8, Table) (28). Each injury category has further subtypes



a.



b. c.

d. e.

f. g.

Figure 8. Young and Burgess classification of pelvic ring injury. Computer-generated images show lateral compression type 1 **(a)**, lateral compression type 2 **(b)**, lateral compression type 3 **(c)**, AP compression type 1 **(d)**, AP compression type 2 **(e)**, AP compression type 3 **(f)**, and vertical shear **(g)** fractures.

on the basis of severity that are determined by the magnitude of the force vector and the resulting degree of displacement of the pelvic ring.

In the acute stage, treatment of patients with pelvic ring injuries who are hemodynamically unstable involves rapidly reducing the fracture and temporarily stabilizing the pelvis until the patient can undergo definitive surgical repair. The method of achieving and maintaining pelvic reduction requires an understanding of the pattern of deformity and the degree of displacement. Methods for temporary reduction and stabilization include placing a pelvic binder or sheet, skeletal traction, external fixation, and placement of a pelvic C-clamp (8). When applied correctly, these methods restore the pelvic ring and reduce pelvic volume to limit ongoing hemorrhage; however, the degree and type of deformity must be known. When applied incorrectly, they may exacerbate the deformity and cause further injury to soft tissues and blood vessels. Understanding the injury force vectors and pattern of displacement allows for optimum treatment through reduction maneuvers and temporary stabilization (29).

Lateral Compression Injury

Lateral compression forces produce the most common pelvic ring injuries. They result from side-impact motor vehicle accidents and falls and are caused by either a direct lateral impact to the innominate bone or indirect transmission of force by way of the hip, which causes internal rotation of the hemipelvis toward the midline. As the hemipelvis internally rotates, the anterior ring breaks through the superior and inferior pubic rami. The distance between the sacrum and the lateral pelvic wall decreases, leaving the sacrotuberus, sacrospinus, and SI ligaments intact. Lateral compression injuries reduce pelvic volume and are generally not associated with substantial hemorrhage unless there is a direct injury to the iliac vessels. In most lateral compression injuries, the pubic rami reveal transverse or horizontally oriented overlapping fractures, with the degree of displacement and the extent of posterior pelvic involvement determining the grade of severity.

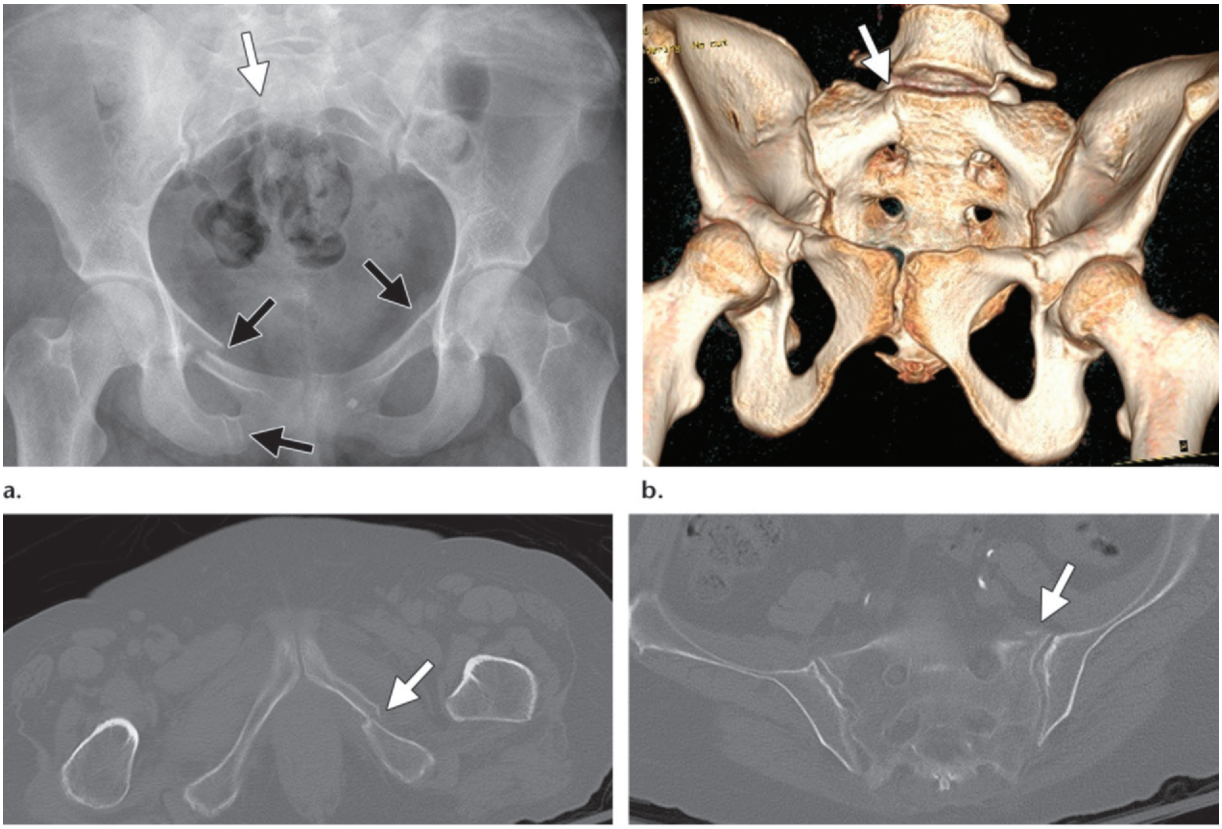
Lateral compression injuries differ depending on the point of application and the magnitude of the inciting force (13). If the force is applied to the posterior aspect of the pelvis, the injury is typically parallel to the trabeculae of the sacrum, with compression or impaction of the cancellous bone of the sacrum. An impaction fracture of the anterior sacrum on the side of the compression is characteristic of a lateral compression type 1 injury, with superior and inferior rami fractures most commonly seen in conjunction with a small "buckle" in the sacral ala (Movie 2). Lateral compression type 1 injuries commonly occur in elderly patients as a result of low-energy falls in the setting of osteopenia or osteoporosis. In these patients, the soft bone often compresses without fully fracturing through the sacrum. The absence of significant vertical displacement makes sacral alar fractures difficult to identify on pelvic radiographs, making it necessary to pay close attention to the sacral neural arches (arcuate lines). Any disruption or angulation of these lines indicates a sacral fracture, although CT is often required to depict posterior fractures (Fig 9) (30). In the absence of significant displacement, lateral compression type 1 injuries are typically stable. Usually, lateral compression type 1 injuries are stable and heal without any surgical intervention, and they are distinct from the high-energy fractures seen in younger patients.

Teaching Point

Lateral compression type 2 injuries occur when the force is directed over the anterior portion of the iliac wing (Movie 3). This force tends to rotate the hemipelvis inward, with the pivot point being the anterior SI joint, and leave a small crescent-shaped segment of posterior ilium firmly attached to the sacrum, a result of a strong posterior SI ligament that leads to a crescent fracture (Fig 10). In younger patients who have strong cancellous bone, it is possible to internally rotate the hemipelvis without creating a posterior fracture of the sacral ala or ilium and to disrupt the posterior SI ligaments instead. At CT, this disruption is seen as widening of the posterior aspect of the SI joint. Lateral compression type 2 injuries are rotationally unstable and, often, vertically stable because the sacrotuberous and sacrospinus ligaments remain intact and limit vertical migration (13).

Lateral compression type 3 injuries occur in the setting of high-energy lateral compression, where the force vector causes internal rotation of the hemipelvis on the side of the impact (as occurs in type 1 and 2 injuries) and a corresponding external rotation of the contralateral hemipelvis. Lateral compression type 3 injuries are also referred to as a "windswept" pelvis (Movie 4). In extreme cases, the entire hemipelvis may be avulsed from the body, resulting in traumatic hemipelvectomy (Fig 11). Lateral compression type 3 injuries are rotationally and vertically unstable, a result of disruption of the sacrospinous, sacrotuberous, and anterior and posterior SI ligaments.

When lateral compression injuries are associated with visceral or vascular damage, it is believed that the internal rotation of the hemipelvis drives the osseous spike of the fractured pubic rami into a branch of the internal iliac artery or



a. b. c. d.

Figure 9. Lateral compression type 1 injury in two patients. **(a)** AP radiograph of the pelvis obtained in a 16-year-old patient who was a backseat passenger in a motor vehicle accident shows bilateral superior and right-sided inferior pubic rami fractures (black arrows) and a subtle disruption of a right sacral arcuate line (white arrow). **(b)** Three-dimensional volume-rendered CT image obtained in the same patient as in **a** shows a zone II fracture disrupting the neuroforamen (arrow), with no widening of the SI joint. **(c)** Axial CT image obtained in a 77-year-old woman who presented with left hip pain after falling on her left side while exiting her car shows an overlapping horizontal inferior pubic ramus fracture (arrow). **(d)** Axial CT image obtained in the same patient as in **c** shows a buckle fracture of the left anterior sacrum (arrow) secondary to compression. No SI joint widening is seen. Both patients were conservatively treated because of the stability of the fracture pattern.

the urinary bladder, resulting in hemorrhage or extraperitoneal bladder rupture. Alternatively, increased intrapelvic pressure may lead to intraperitoneal bladder rupture (Fig 12). Posteriorly, a compression injury of the sacrum through the foramina may compress the sacral nerve roots (23). Iliac crescent fractures may also extend to the greater sciatic foramen, with injury to the sciatic or superior gluteal nerve (10).

AP Compression Injury

Forces on the pelvis that are directed anterior to posterior in the sagittal plane may result from head-on motor vehicle accidents, motorcycle accidents, falls, and crush injuries. They typically produce external rotation of one or both hemipelvises, with the fulcrum of rotation at the SI joints leading to an “open-book” or “spring pelvis” type of injury. External rotation of the hemipelvis causes the iliac wing to appear broader than normal on AP radiographs (12).

In AP compression injuries, the first point of failure is the pubic symphysis, which is either disrupted or surrounded by vertical fractures through one or both pairs of pubic rami, a finding indicative of an AP compression type 1 injury. In type 2 injuries, further external rotation spreads the pelvis open, with failure of the sacrotuberous, sacrospinous, and anterior SI ligaments under tension and ultimate failure of the posterior SI ligaments in more severe type 3 injuries (5). It is imperative that radiologists understand that preoperative placement of a pelvic binder or sheet may reduce the deformity, making it difficult to detect at imaging, especially in the absence of fractures. However, the pubic symphysis usually does not reduce to perfect alignment, and careful inspection may reveal slight superior displacement of one side of the symphysis (10).

In AP compression type 1 injuries, diastasis of the pubic symphysis is less than 2.5 cm and may occur without rupture of the posterior ligaments

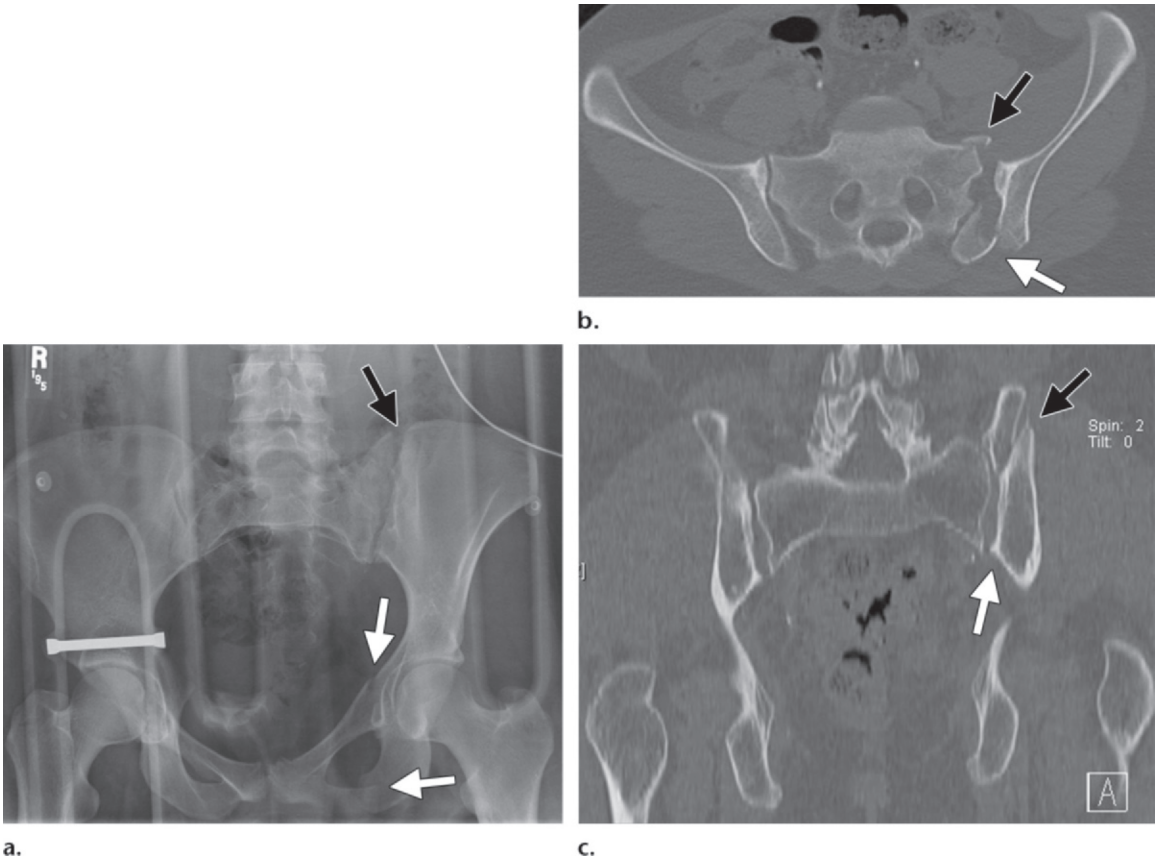


Figure 10. Lateral compression type 2 injury in an 18-year-old woman who was an unrestrained driver in a motor vehicle accident. **(a)** Pelvic radiograph shows left-sided overlapping superior and inferior pubic rami fractures (white arrows) and widening of the left SI joint (black arrow). **(b)** Axial CT image shows a fracture of the anterior sacrum at the site of the anterior SI ligament attachment (black arrow) and widening of the SI joint. A crescent fracture (white arrow) involving the left iliac bone is also seen. The posterior SI ligament is keeping the fragment attached to the sacrum. **(c)** Coronal CT image obtained at the level of the posterior SI joint shows the crescent fracture (black arrow). No craniocaudal displacement of the iliac bone (white arrow) is seen, a finding that excludes vertical shear injury. The patient underwent open reduction and internal fixation of the left SI joint.

of the pelvis, resulting in injuries that are rotationally and vertically stable because of the intact posterior ring (Fig 13) (Movie 5). However, because pure AP compression type 1 injuries are rare, patients with any degree of pubic symphysis diastasis must be treated as if a posterior pelvic injury is present until it is proved otherwise (10).

Teaching Point

AP compression type 2 fractures are associated with some degree of posterior instability, a result of injury to the anterior SI complex and the sacrotuberous and sacrospinous ligaments, allowing for more than 2.5 cm of symphyseal diastasis and anterior SI widening (Movie 6). Because the posterior SI ligaments remain intact, AP compression type 2 injuries are rotationally unstable and vertically stable (Fig 14). Subtle widening of the anterior SI joint space is often difficult to assess at radiography. The presence of an L5 transverse process fracture may be the only indication of a posterior ring injury and is an independent predictor of instability (Fig 7) (31). Therefore, it is imperative that the radiologist look for subtle bilateral anterior SI joint asymmetry and an occult L5 transverse process fracture at radiography or CT because it may represent a rotationally unstable injury.

In AP compression type 3 injuries, there is complete disruption of the posterior SI ligament, with separation of the iliac wing from the sacrum and both rotational and vertical instability (Fig 15) (Movie 7). The distinction between anterior and posterior SI diastasis is often better appreciated on axial CT images, with posterior displacement of the iliac bone indicating posterior sacroiliac disruption and associated vertical instability. The distractive forces at the level of the SI joints may also cause adjacent damage to the internal iliac vessels and lumbosacral plexus.

Substantial hemorrhage and arterial bleeding are most prevalent with AP compression injuries, and the severity may be determined on the basis of whether active extravasation is present on arterial phase images or whether a large volume of pelvic

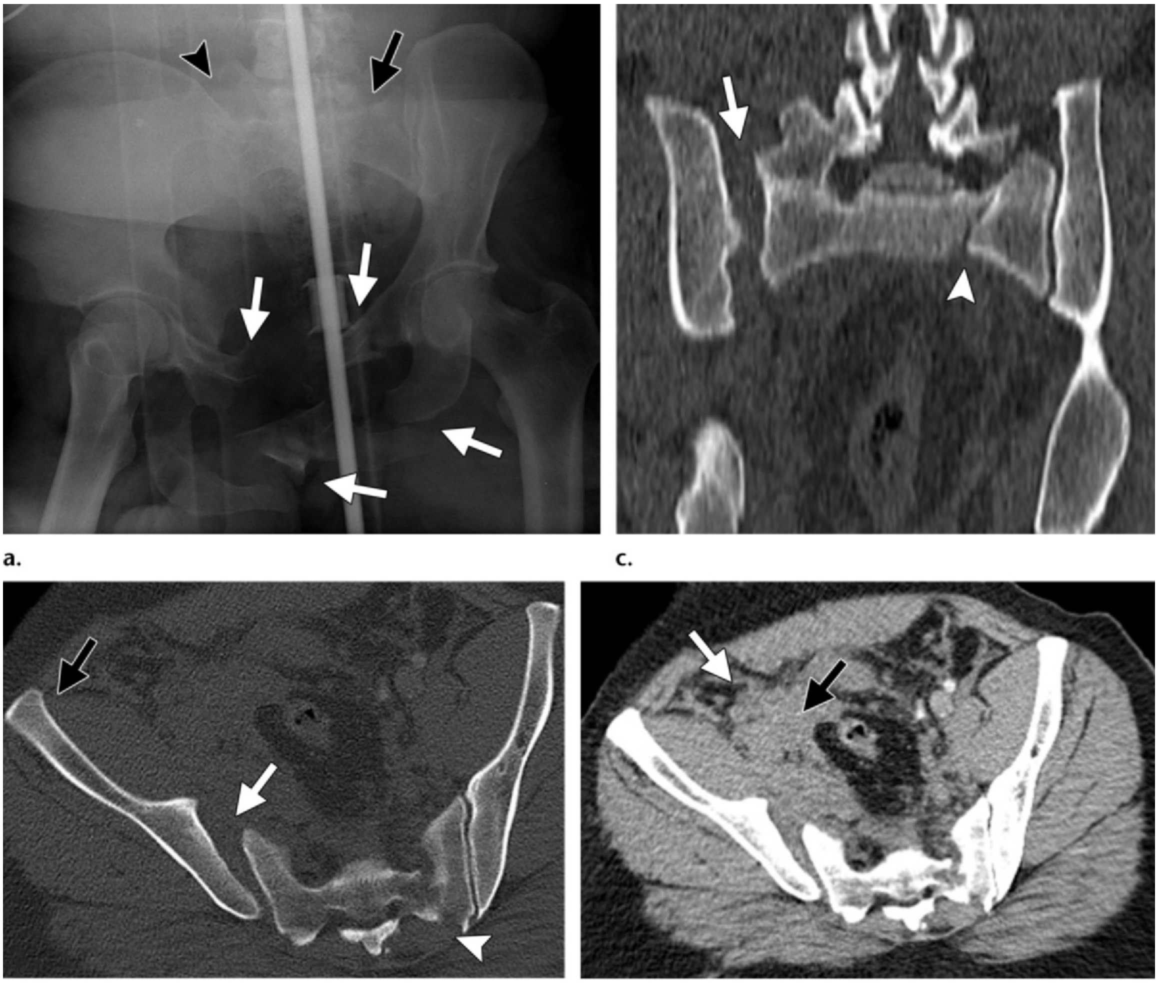


Figure 11. Lateral compression type 3 injury in a 28-year-old male pedestrian who was struck by a truck moving at high speed. **(a)** AP radiograph of the pelvis shows a medialized left hemipelvis, fractures of the bilateral superior and inferior pubic rami (white arrows), and a compression fracture through the left sacrum (black arrow), a finding consistent with a lateral compression injury. Gross widening of the contralateral right SI joint (arrowhead) with external rotation of the right iliac wing is also seen, findings indicative of a "windswept pelvis" injury. **(b, c)** Axial **(b)** and coronal **(c)** CT images show an impaction fracture of the left sacrum (arrowhead) secondary to a compression force and external rotation on the right (black arrow in **b**), with right SI joint dissociation (white arrow) and relative anterior displacement of the right iliac bone, findings indicative of an AP compression type 3 injury. **(d)** Axial CT image obtained with soft-tissue window settings shows a large right-sided extraperitoneal hematoma (black arrow) and a lack of opacification in the right internal and external iliac arteries (white arrow). The patient was found to have avulsion of both vessels and underwent emergent laparotomy for hemorrhage control and right hemipelvectomy.

hemorrhage is present. The presence of more than 500 mL of extraperitoneal hemorrhage has been found to correspond with a 50% probability of pelvic arterial injury (32). The arteries that are most frequently severed are the superior gluteal (in posterior pelvic injuries) and the internal pudendal (in anterior pelvic arch injuries) arteries. AP compression injuries with severed arteries are associated with high rates of morbidity and mortality.

Vertical Shear Injury

Vertical shear fractures are caused by cranially directed high-energy forces from violent axial loading of the hemipelvis, such as occurs when one falls from a height and lands on an extended leg. The exact fracture pattern depends on both the amount of force applied and the relative strength of the bone and ligamentous structures (13). In patients with greater bone strength, ligamentous injuries are usually seen as pubic symphysis and SI joint disruptions (Fig 16). In patients with weaker bones, the bones yield first, resulting in vertically oriented pubic rami fractures anteriorly and sacral fractures posteriorly (Movie 8). Sacral fractures characteristically extend from the sacral notch obliquely to the midportion of the body of

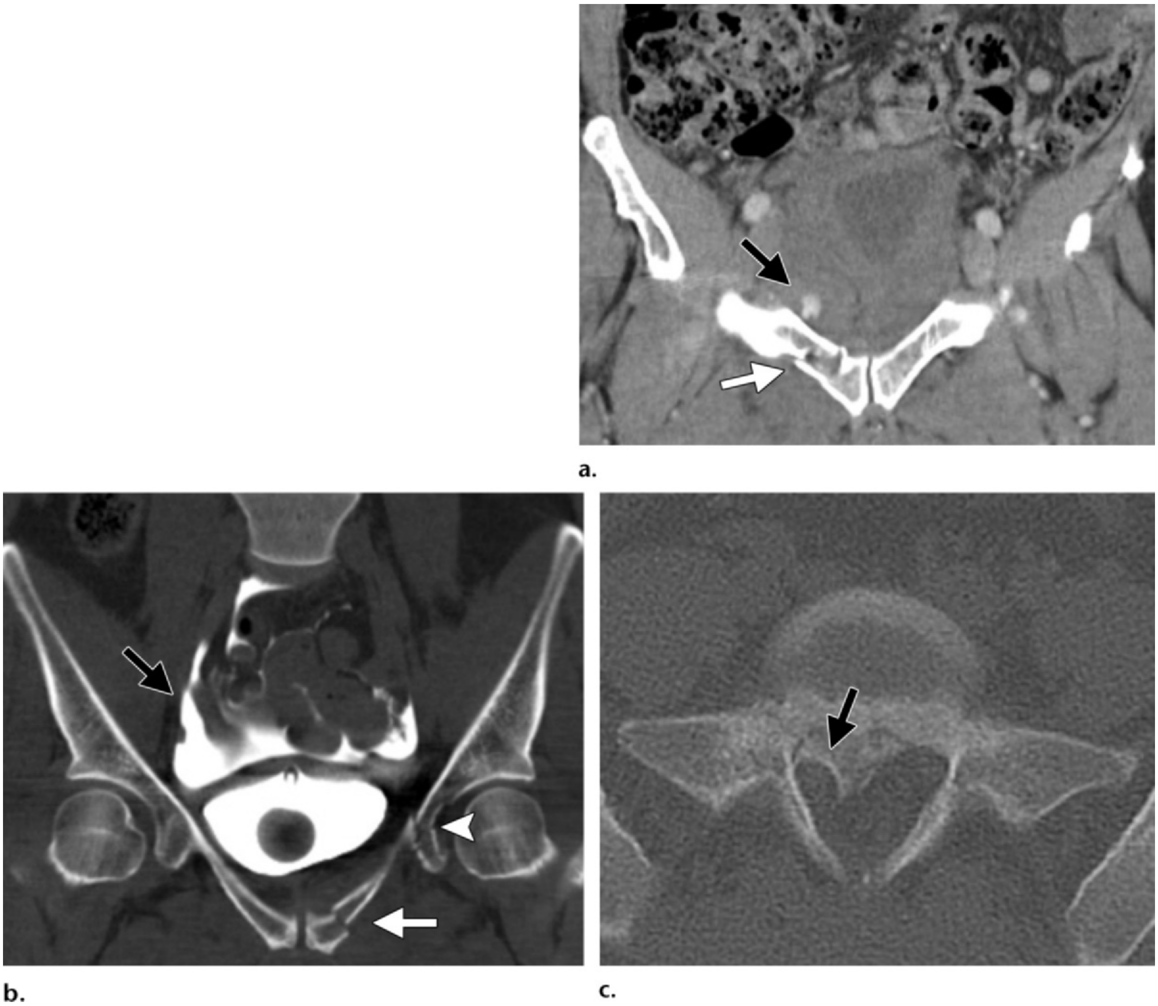
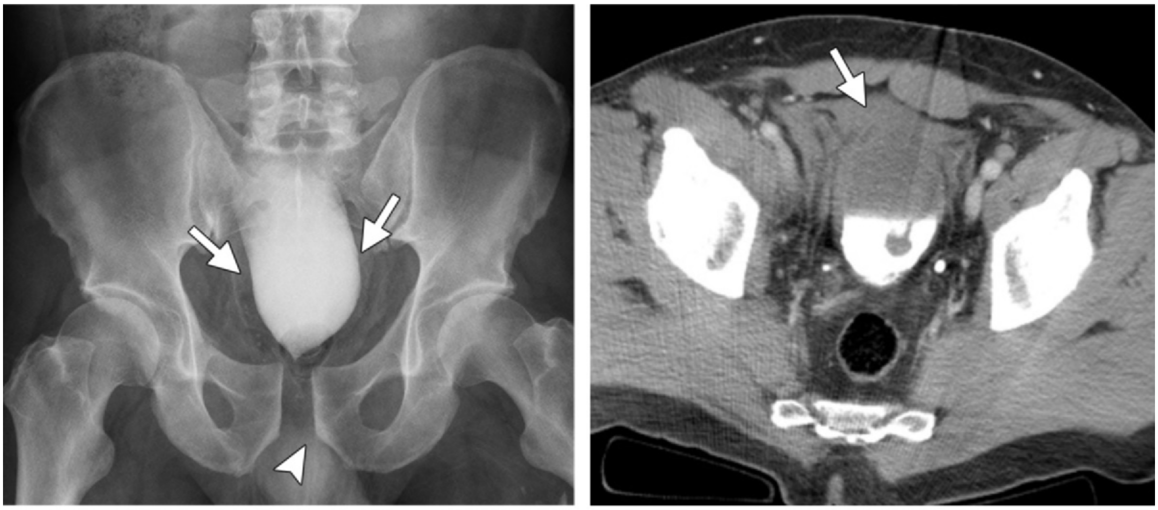


Figure 12. Complications of lateral compression injuries in three patients. **(a)** Coronal CT image obtained at the level of the pelvis in a 33-year-old woman shows active extravasation of contrast material from an internal iliac artery branch (black arrow), a result of a direct bone injury. Note the overlapping pubic ramus fracture (white arrow), a finding in keeping with a lateral compression injury. **(b)** Coronal CT cystogram obtained in a 22-year-old man shows leakage of contrast material into the peritoneal cavity (black arrow), a finding consistent with intraperitoneal rupture of the urinary bladder, a result of increased pressure from a lateral compression. Note the fractures of the superior pubic ramus (white arrow) and medial acetabular wall (arrowhead), signs of a severe injury. **(c)** Axial CT image obtained at the level of the sacrum in a 40-year-old woman with a lateral compression type 1 injury shows a sacral osseous fragment compressing the sacral nerve roots (arrow).

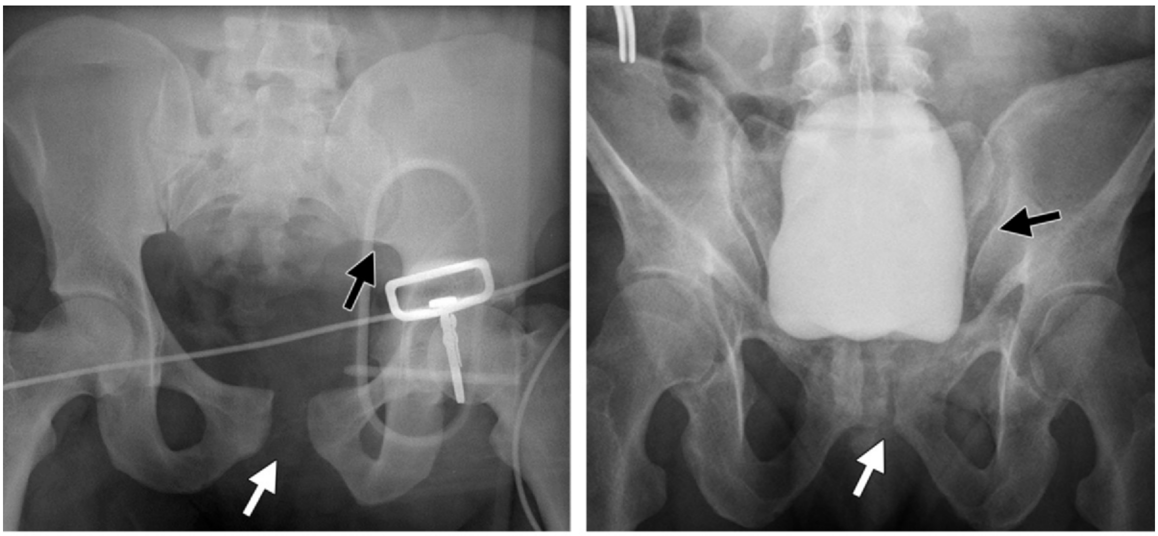
the first sacral segment (12). Severe vertical shear injuries may be mistaken for AP compression type 3 injuries because both lead to a disarticulated hemipelvis. The key imaging finding of vertical shear injury is a cephalad displacement of the iliac crest of the injured hemipelvis relative to the opposite side. It is important for the radiologist to look for vertical displacement at the inferior margin of the SI joint, which signifies disruption of the posterior SI ligament secondary to vertical shear. In contrast, vertical displacement at only the pubic symphysis does not necessarily indicate a vertically unstable pelvis because obturator ring fractures may create a floating medial pubic fragment that

Figure 14. AP compression type 2 injury in a 54-year-old male construction worker who sustained a crush injury to his pelvis after an 800-lb forklift fell on his prone body. **(a, b)** AP **(a)** and outlet **(b)** radiographs of the pelvis show pubic symphysis diastasis (white arrow), significant asymmetric widening of the left SI joint (black arrow), and broadening of the left iliac wing. These findings are suggestive of an open hemipelvis, which is seen in AP compression type 2 injuries. **(c)** Axial CT image shows widening of the SI joint and a small avulsion fragment (arrow) at the site of the anterior SI ligament attachment. **(d)** Axial CT image obtained with soft-tissue window settings shows an intact anterior SI ligament on the right (black arrow) and disruption on the left. The posterior SI ligaments are intact (white arrows). Open reduction and internal fixation of the anterior pelvic ring were performed, resulting in correction of the pubic diastasis and spontaneous reduction of the SI joint.



a. b.

Figure 13. AP compression type 1 injury in a 53-year-old man who sustained a segmental femur fracture in a skydiving accident and was transferred from an outside hospital after undergoing CT of the abdomen and pelvis. **(a)** AP radiograph of the pelvis shows pubic symphysis diastasis of 1.5 cm (arrowhead) and no apparent posterior pelvic ring injury, findings consistent with an AP compression type 1 injury. The contrast material–filled bladder appears to be vertically narrowed (arrows), a finding suggestive of pelvic hemorrhage. **(b)** Axial CT image shows a small area of extraperitoneal hemorrhage (arrow) surrounding the bladder. An intact posterior ring was found at surgery, and open reduction and internal fixation of only the anterior ring were performed.



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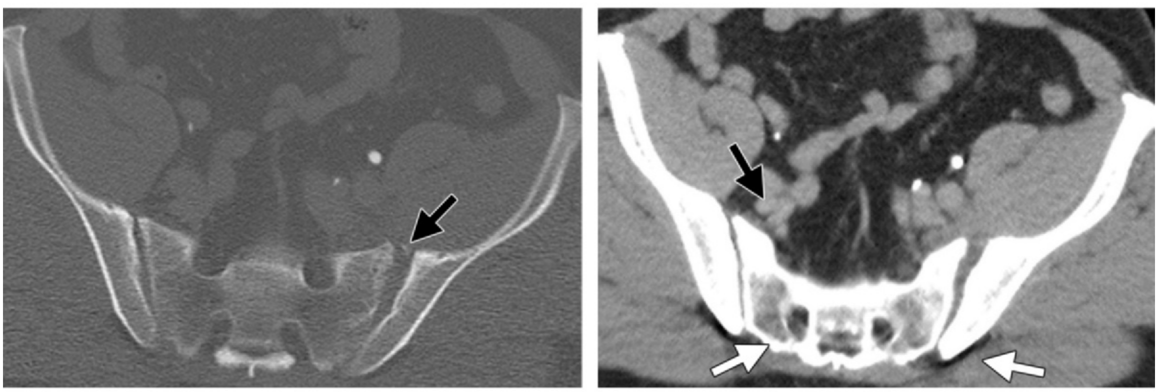
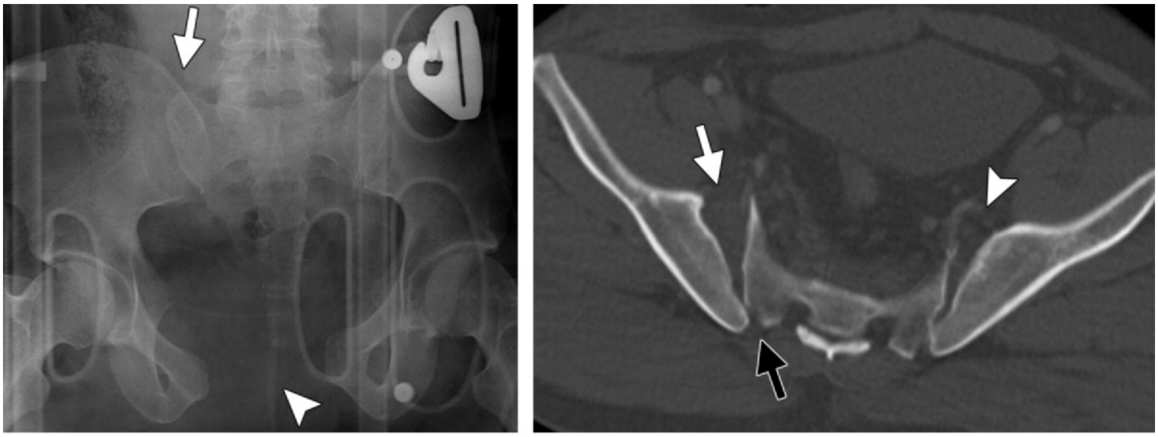


c. d.



a. b.

Figure 15. Pelvic AP radiograph **(a)** and axial CT image **(b)** obtained in a 31-year-old man show gross pubic symphysis diastasis (arrowhead in **a**) and significant widening of the right SI joint (white arrow). The resulting external rotation of the right hemipelvis is characteristic of AP compression. The slight posterior displacement of the right iliac side of the SI joint suggests posterior ring ligamentous disruption (black arrow in **b**), a finding consistent with an AP compression type 3 injury. Mild widening of the left SI joint is also seen (arrowhead in **b**).

a. b.

c.

Figure 16. Vertical shear in an 80-year-old woman who sustained a pelvic injury after a mechanical fall. **(a)** AP radiograph of the pelvis shows widening of the pubic symphysis (white arrow) and left SI joint (black arrow), with relative cranial displacement of the left hemipelvis, findings consistent with a vertical shear injury. **(b)** Coronal CT image shows the vertical displacement (arrow). **(c)** Postoperative AP radiograph shows anterior stabilization of the pubic symphysis and posterior ring stabilization of the left SI joint.

is displaced vertically or their angle of projection may cause them to simulate vertical displacement (10). Because of the anterior tilt of the pelvic ring, inlet and outlet radiographic views and CT best depict cranial and posterior displacement of the iliac bone relative to the sacrum. In addition, severe SI joint widening with pubic symphysis diastasis of less than 2.5 cm suggests vertical shear as the mechanism of injury rather than AP compression. Vertical shear injuries are both vertically and rotationally unstable and are often associated with other visceral injuries, making early detection critical to best direct further imaging. CT cystography

a. b. c. d.

Figure 17. Vertical shear injury in a 54-year-old man who lost engine power at 100 feet above ground while flying his ultralight plane and crash landed in a wooded area. **(a)** AP radiograph of the pelvis shows widening of the pubic symphysis (white arrow), left and right (black arrow) sacral fractures, and a fracture of the transverse L5 process (arrowhead). **(b)** Coronal CT cystogram shows pelvic hemorrhage (arrow) but no evidence of leakage. **(c)** Intraoperative retrograde urethrogram shows disruption of the prostatic urethra and extravasation of contrast material extending into the Retzius space (arrow). **(d)** Postoperative radiograph shows internal fixation of the anterior and posterior arches and a urethral catheter.

is recommended for evaluation of the bladder in the setting of pelvic fracture and hematuria. In the absence of a contrast material leak, retrograde urethrography may be required to exclude urethral injury, especially in the presence of hematuria. Typically, urethral rupture occurs at the apex of the prostate at the junction of the prostatic and membranous urethra, above the urogenital diaphragm (Fig 17) (33).

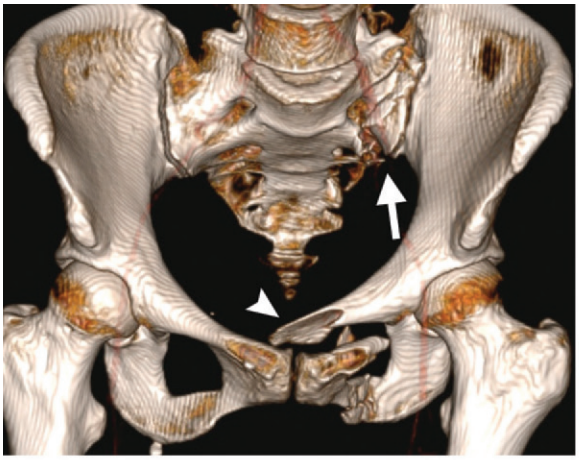
Combined Mechanism Injury

The combined mechanism category of injury is reserved for pelvic fractures that demonstrate elements of more than one pattern. In general, these injuries result from very high energies, and patients often present with significant displacement. The most common type of combined mechanism injury is a lateral compression and vertical shear injury (Fig 18).

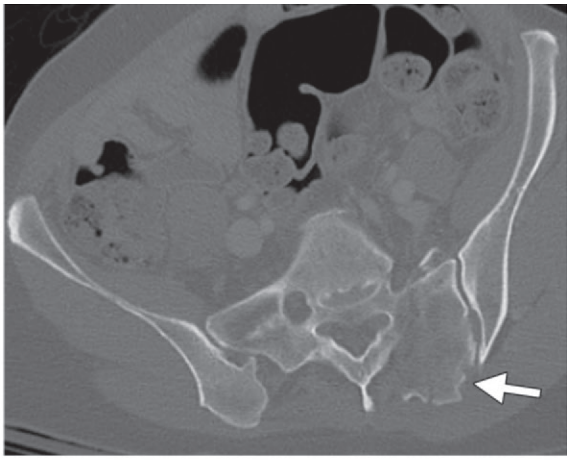
Conclusion

The central challenge for the orthopedic surgeon evaluating a patient with pelvic fractures is to determine the causative forces and their underlying biomechanical implications, because they help define management and affect the overall prognosis.

Figure 18. Combined lateral compression and vertical shear injury in a 53-year-old woman involved in a motor vehicle accident. **(a)** Three-dimensional volume-rendered CT image shows medialization of the left hemipelvis with overlapping horizontal fractures of the pubic rami (arrowhead), findings consistent with a lateral compression injury. A cranially displaced oblique sacral fracture (arrow) is also seen and is characteristic of a vertical shear injury. **(b)** Axial CT image shows the oblique sacral fracture (arrow) extending from the sacral notch to the body. These findings are indicative of a combined lateral compression and vertical shear injury. Anterior and posterior ring fixation were performed. **(c)** AP radiograph obtained after open reduction and internal fixation of the posterior ring injury shows a supraacetabular pedicle screw internal fixation construct for the anterior pelvic ring. The internal fixation construct is reported to be stiffer than an external fixator and permits patients to sit, roll over in bed, and lie on their sides without the complications associated with external fixation devices (34).



a.



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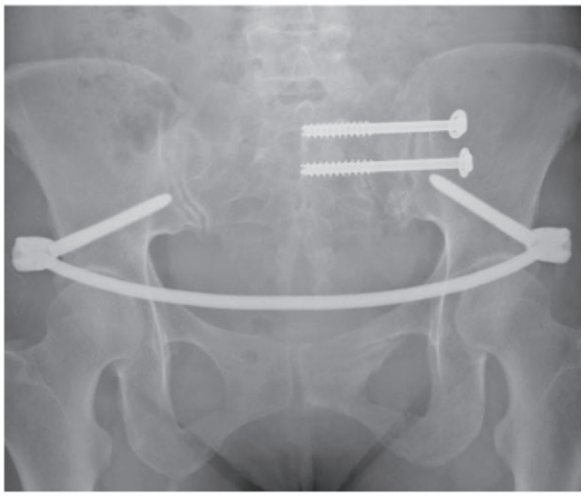

c.

An understanding of the Young and Burgess classification system enables radiologists to better evaluate pelvic ring injuries, potentially improving the detection of subtle but critical imaging findings, and may direct further imaging to look for associated musculoskeletal and visceral injuries.

***Disclosures of Conflicts of Interest.*—M.J.W.** *Activities related to the present article:* disclosed no relevant relationships. *Activities not related to the present article:* CME course faculty for the AO Foundation. *Other relationships:* disclosed no relevant relationships.

References

1. Schmal H, Markmiller M, Mehlhorn AT, Sudkamp NP. Epidemiology and outcome of complex pelvic injury. Acta Orthop Belg 2005;71(1):41–47.
2. McCormack R, Strauss EJ, Alwattar BJ, Tejwani NC. Diagnosis and management of pelvic fractures. Bull NYU Hosp Jt Dis 2010;68(4):281–291.
3. Ben-Menachem Y, Coldwell DM, Young JW, Burgess AR. Hemorrhage associated with pelvic fractures: causes, diagnosis, and emergent management. AJR Am J Roentgenol 1991;157(5):1005–1014.
4. White CE, Hsu JR, Holcomb JB. Haemodynamically unstable pelvic fractures. Injury 2009;40(10): 1023–1030.
5. Durkin A, Sagi HC, Durham R, Flint L. Contemporary management of pelvic fractures. Am J Surg 2006;192(2):211–223.
6. Dyer GS, Vrahas MS. Review of the pathophysiology and acute management of haemorrhage in pelvic fracture. Injury 2006;37(7):602–613.
7. Cullinane DC, Schiller HJ, Zielinski MD, et al. Eastern Association for the Surgery of Trauma practice management guidelines for hemorrhage in pelvic fracture: update and systematic review. J Trauma 2011;71(6):1850–1868.
8. Jeske HC, Larndorfer R, Krappinger D, et al. Management of hemorrhage in severe pelvic injuries. J Trauma 2010;68(2):415–420.
9. Figler B, Hoffler CE, Reisman W, et al. Multi-disciplinary update on pelvic fracture associated bladder and urethral injuries. Injury 2012;43(8):1242–1249.
10. Stambaugh LE 3rd, Blackmore CC. Pelvic ring disruptions in emergency radiology. Eur J Radiol 2003; 48(1):71–87.
11. Kurylo JC, Tornetta P 3rd. Initial management and classification of pelvic fractures. Instr Course Lect 2012;61:3–18.
12. Rogers LF. Pelvic trauma. In: Radiology of skeletal trauma. 3rd ed. Philadelphia, Pa: Churchill Livingstone, 2002; 930–1029.

13. Stover MD, Mayo KA, Kellam JF. Pelvic ring disruptions. In: Skeletal trauma: basic science, management, and reconstruction. 4th ed. Philadelphia, Pa: Saunders, 2009; 1107–1170.
14. Kellam JF, Mayo KA. Pelvic ring disruption. In: Skeletal trauma. 3rd ed. Philadelphia, Pa: Saunders; 1052–1108.
15. Edeiken-Monroe BS, Browner BD, Jackson H. The role of standard roentgenograms in the evaluation of instability of pelvic ring disruption. Clin Orthop Relat Res 1989 (240):63–76.
16. Campbell SE. Radiography of the hip: lines, signs, and patterns of disease. Semin Roentgenol 2005;40 (3):290–319.
17. Resnik CS, Stackhouse DJ, Shanmuganathan K, Young JW. Diagnosis of pelvic fractures in patients with acute pelvic trauma: efficacy of plain radiographs. AJR Am J Roentgenol 1992;158(1): 109–112.
18. Park JS, Resnick CS. Imaging of pelvic trauma. Contemporary Diagnostic Radiology 2005;20(24): 1–6.
19. Gary JL, Mulligan M, Banagan K, Sciadini MF, Nascone JW, O'Toole RV. Magnetic resonance imaging for the evaluation of ligamentous injury in the pelvis: a prospective case-controlled study. J Orthop Trauma 2014;28(1):41–47.
20. Weaver MJ, Bruinsma W, Toney E, Dafford E, Vrahas MS. What are the patterns of injury and displacement seen in lateral compression pelvic fractures? Clin Orthop Relat Res 2012;470(8): 2104–2110.
21. Pennal GF, Tile M, Waddell JP, Garside H. Pelvic disruption: assessment and classification. Clin Orthop Relat Res 1980 (151):12–21.
22. Osgood GM, Manson TT, O'Toole RV, Turen CH. Combined pelvic ring disruption and acetabular fracture: associated injury patterns in 40 patients. J Orthop Trauma 2013;27(5):243–247.
23. Tile M, Hearn T, Vrahas MS. Biomechanics. In: Fractures of the pelvis and acetabulum. 3rd ed. Philadelphia, Pa: Lippincott Williams & Wilkins, 2003; 32–45.
24. Burgess AR, Eastridge BJ, Young JW, et al. Pelvic ring disruptions: effective classification system and treatment protocols. J Trauma 1990;30(7): 848–856.
25. Kregor PJ, Routt ML Jr. Unstable pelvic ring disruptions in unstable patients. Injury 1999;30(suppl 2):B19–B28.
26. Young JW, Burgess AR, Brumback RJ, Poka A. Pelvic fractures: value of plain radiography in early assessment and management. Radiology 1986;160(2): 445–451.
27. Dalal SA, Burgess AR, Siegel JH, et al. Pelvic fracture in multiple trauma: classification by mechanism is key to pattern of organ injury, resuscitative requirements, and outcome. J Trauma 1989;29(7): 981–1000; discussion 1000–1002.
28. Gänsslen A, Pohlemann T, Paul C, Lobenhoffer P, Tscherne H. Epidemiology of pelvic ring injuries. Injury 1996;27(suppl 1):S13–S20.
29. Young JW, Resnik CS. Fracture of the pelvis: current concepts of classification. AJR Am J Roentgenol 1990;155(6):1169–1175.
30. Scheyerer MJ, Osterhoff G, Wehrle S, Wanner GA, Simmen HP, Werner CM. Detection of posterior pelvic injuries in fractures of the pubic rami. Injury 2012;43(8):1326–1329.
31. Starks I, Frost A, Wall P, Lim J. Is a fracture of the transverse process of L5 a predictor of pelvic fracture instability? J Bone Joint Surg Br 2011;93(7): 967–969.
32. Blackmore CC, Jurkovich GJ, Linnau KF, Cummings P, Hoffer EK, Rivara FP. Assessment of volume of hemorrhage and outcome from pelvic fracture. Arch Surg 2003;138(5):504–508.
33. Sandler CM, Harris JH Jr, Corriere JN Jr, Toombs BD. Posterior urethral injuries after pelvic fracture. AJR Am J Roentgenol 1981;137(6):1233–1237.
34. Vaidya R, Colen R, Vigdorchik J, Tonnos F, Sethi A. Treatment of unstable pelvic ring injuries with an internal anterior fixator and posterior fixation: initial clinical series. J Orthop Trauma 2012;26(1): 1–8.

Pelvic Ring Fractures: What the Orthopedic Surgeon Wants to Know

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The posterior SI ligament is a key vertical stabilizer, maintaining the sacrum in its normal position in the pelvic ring (14). The posterior pelvis and sacrum are the keystone elements of the pelvis because they provide structural support and stabilization of the entire pelvic ring.

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The pubic symphysis is stabilized by a series of ligaments and primarily serves as a strut to improve anterior ring stability during ambulation. However, the pubic symphysis is the weakest link in the pelvic ring, contributing only 15% of intrinsic pelvic stability (5,11).

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Pelvic ring fractures or dislocations that include significant posterior displacement or disruption of the posterior SI ligaments are much more unstable. In these injuries, the hemipelvis and limb are completely disconnected from the axial skeleton, and the hemipelvis is free to rotate internally or externally and to migrate proximally. These injuries are referred to as being globally or vertically unstable and are associated with neurovascular injury and a higher rate of further displacement if left untreated. Other secondary signs of instability are avulsion fractures of the sacrospinous or iliolumbar ligaments and L5 transverse process avulsion fractures, which indicate that the pelvis was more significantly displaced at the time of injury (Fig 7).

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Usually, lateral compression type 1 injuries are stable and heal without any surgical intervention, and they are distinct from the high-energy fractures seen in younger patients.

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However, because pure AP compression type 1 injuries are rare, patients with any degree of pubic symphysis diastasis must be treated as if a posterior pelvic injury is present until it is proved otherwise (10).