Acetabular Fractures: What Radiologists Should Know and How 3D CT Can Aid Classification[1]

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Correct recognition, description, and classification of acetabular fractures is essential for efficient patient triage and treatment. Acetabular fractures may result from high-energy trauma or low-energy trauma in the elderly. The most widely used acetabular fracture classification system among radiologists and orthopedic surgeons is the system of Judet and Letournel, which includes five elementary (or elemental) and five associated fractures. The elementary fractures are anterior wall, posterior wall, anterior column, posterior column, and transverse. The associated fractures are all combinations or partial combinations of the elementary fractures and include transverse with posterior wall, T-shaped, associated both column, anterior column or wall with posterior hemitransverse, and posterior column with posterior wall. The most unique fracture is the associated both column fracture, which completely dissociates the acetabular articular surface from the sciatic buttress. Accurate categorization of acetabular fractures is challenging because of the complex three-dimensional (3D) anatomy of the pelvis, the rarity of certain acetabular fracture variants, and confusing nomenclature. Comparing a 3D image of the fractured acetabulum with a standard diagram containing the 10 Judet and Letournel categories of acetabular fracture and using a flowchart algorithm are effective ways of arriving at the correct fracture classification. *Online supplemental material is available for this article.*

Abbreviations: AO = Arbeitsgemeinschaft für Osteosynthesefragen, MDCT = multidetector CT, OTA = Orthopedic Trauma Association, 3D = three-dimensional

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SA-CME LEARNING OBJECTIVES

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

- Describe the 10 categories of acetabular fracture in the Judet and Letournel classification system.
- List supplemental bone and soft-tissue findings that may be important for surgical repair of acetabular fractures.
- Discuss the complications of acetabular fractures.

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Introduction

Judet and Letournel (1) were disappointed with both operative and nonoperative outcomes of acetabular fractures, so in the 1960s they developed standardized imaging protocols with which to classify acetabular fractures. After intensive research into the complex anatomy and radiographic landmarks of the acetabulum, they developed an acetabular fracture classification system that remains in use today (1).

Many factors make classification of acetabular fractures complicated. Such injuries are uncommon, making mastery of their diagnosis difficult (2). They are more commonly seen in level 1 trauma centers, where many radiologists do not practice or have not completed their training. The pelvis is a complex three-dimensional (3D)

TEACHING POINTS

- The five elementary fracture types are posterior wall, anterior wall, posterior column, anterior column, and transverse. The five associated fracture types are combinations or partial combinations of the elementary fractures and include transverse with posterior wall, posterior column with posterior wall, T-shaped, anterior column or wall with posterior hemitransverse, and associated both column.
- Because a posterior wall fracture only involves the posterior articular surface, it is not seen on the medial acetabular surface.
- Although a transverse acetabular fracture is "transverse," on axial CT images the fracture line is in the sagittal plane, with the fracture line typically crossing from medial to lateral when one scrolls through images from cranial to caudal. This occurs because the acetabulum is imaged anatomically, and it is classically described with the acetabulum facing laterally and the acetabular notch facing inferiorly. When the most lateral extent of the fracture is viewed on axial CT images, it may appear as distinct anterior and posterior wall fractures. Therefore, 3D images must be constructed, or axial images must be summated in one's mind while scrolling through a series of axial images, to appreciate the true transverse nature of this fracture pattern.
- Associated both-column fractures are unique in that the entire weight-bearing portion of the acetabulum is disconnected from the sciatic buttress.
- Our preferred method is to classify the fracture on the basis of surface-rendered 3D images. Although it may take a few extra minutes to construct the 3D model, we believe there are substantial benefits of higher confidence and greater accuracy.

bone that, because of overlap with itself and with the femur, has surfaces that are not easily visible on standard frontal and lateral projections. Last and possibly most important, fracture nomenclature is complicated and not intuitive. Fractures are described relative to the orientation of the acetabulum viewed en face from the lateral side, whereas, in the anatomic position, the acetabulum is tilted inferiorly and anteriorly, making its appearance at radiography and planar computed tomography (CT) nonintuitive relative to the nomenclature (3). For example, although the superior pubic ramus is superior, when viewing the acetabulum en face it is anterior. Furthermore, transverse fractures of the acetabulum are predominantly transverse in the acetabular plane but are actually sagittal oblique (with the medial aspect superior to the lateral aspect) in the anatomic plane. Fracture nomenclature is also not intuitive. For example, transverse acetabular fractures traverse both columns but are not classified as "associated both column" fractures; the term *associated both column fracture* is reserved for a fracture pattern in which the acetabular articular surface is no longer continuous with the intact ilium and is completely separate from the sciatic buttress.

The importance of understanding acetabular fractures cannot be minimized. The lower extremity supports the axial skeleton by way of the acetabulum. Failure to diagnose, classify, or properly repair these fractures results in hip instability and posttraumatic osteoarthritis.

In this review, we begin by discussing the development and anatomy of the acetabulum and continue with descriptions of acetabular fracture classification systems. We then describe how acetabular fractures can be imaged and classified. Detailed analysis of acetabular imaging was previously described, and although we make occasional references to radiography and planar CT, we primarily focus on classifying fractures with surface-rendered 3D multidetector CT (MDCT) images (4–7). We conclude with a discussion of surgical implications and complications of acetabular fractures that are relevant to radiologists.

Development of the Acetabulum

A fully developed hip joint is present by 8 weeks gestation (8). Enchondral ossification commences with formation of primary ossification centers within the ilium, ischium, and pubis between 9 and 20 weeks gestation (8,9). The triradiate cartilage separates these developing bones, and the articular cartilage lines the acetabulum (10,11). The triradiate cartilage has three flanges: an anterior flange separates the ilium and pubis, a posterior flange separates the ilium and ischium, and a vertical flange separates the pubis and ischium. The triradiate cartilage is relatively wide at birth but narrows to 5–6 mm during childhood and adolescence (Fig 1) (10). The primary ossification centers continue to lay down new bone adjacent to the triradiate cartilage, causing radial expansion of the acetabular cup congruent to the adjacent femoral head (12). The presence of the femoral head is necessary for normal acetabular development. The ilium, ischium, and pubis fuse by about 13–16 years of age, with ultimate obliteration of the triradiate cartilage.

Three main secondary ossification centers are also fundamental in formation of the mature acetabulum. They form at 8–9 years of age and are primarily responsible for the bone that develops into the acetabular rims and the inverted U-shaped acetabular articular surface (9,12). The os acetabuli is anterior and adjacent to the anterior flange of the triradiate cartilage, the small posterior epiphysis is posterior and adjacent to the posterior flange of the triradiate cartilage, and the acetabular epiphysis forms superiorly and extends out of the acetabulum and constitutes a portion of the anterior inferior iliac spine (9). These centers unite with the acetabulum by 17–18 years of age, forming the adult acetabulum (12).

a. b. c.

Figure 1. Three stages of acetabular development. **(a)** Surface-rendered 3D MDCT image of the left acetabulum obtained in a 4-month-old girl shows the ilium *(Il)*, ischium *(Is)*, and pubis *(P)* as three separate bones separated by the nonossified triradiate cartilage. **(b)** Surface-rendered 3D MDCT image of the left acetabulum obtained in a 4-year-old boy shows that the triradiate cartilage has thinned but the ilium (*Il*), ischium (*Is*), and pubis (*P*) are still separate. **(c)** Surface-rendered 3D MDCT image of the left acetabulum obtained in a 10-year-old girl shows that the acetabulum has almost completely ossified, with its three component bones now forming the innominate bone. *Il* = ilium, *Is* = ischium, *P* = pubis.

Anatomy of the Acetabulum

The adult acetabulum contains components of the ilium, ischium, and pubis, which together form the innominate bone (5,13). The acetabulum contains anterior and posterior walls (or rims) but is open inferiorly as the acetabular notch (Fig 2, Movie 1). There is an upside-down U-shaped hyaline cartilage–covered articular surface that contacts the femoral head. The central nonarticular portion of the "U" is termed the *cotyloid fossa* and contains fatty pulvinar and the ligamentum teres (5). The fibrocartilagenous acetabular labrum lines the anterior, superior, and posterior acetabular rims, thereby deepening the acetabulum and helping resist dislocation of the femoral head. The acetabular labrum is bridged inferiorly by the transverse acetabular ligament (13). The flat medial surface of the acetabulum that faces the pelvic organs is named the quadrilateral plate or surface.

The sciatic buttress lies along the superior posteromedial portion of the innominate bone, adjacent to the sacroiliac joint. When an orthopedic surgeon fixes an acetabular fracture, the fracture is built back to this portion of the intact ilium. The acetabulum articulates with the femoral head, coupling the axial and appendicular skeletons by way of the the sciatic buttress. The sciatic buttress is the confluence of the anterior and posterior columns of the acetabulum. Together, the columns form a lowercase lambda (λ) shape, with a longer anterior column and a shorter posterior column (Fig 2) (5,14,15). Anterior and posterior column support of the acetabulum is essential when considering internal fixation of acetabular fractures (4,16). The anterior column includes the anterior border of the iliac wing, the pelvic brim, the anterior superior iliac spine, the anterior inferior iliac spine, the anterior wall of the acetabulum, and the superior pubic ramus. The posterior column includes only the ischial portion of the innominate bone, including the greater and lesser sciatic notches, the posterior wall of the acetabulum, and the ischial tuberosity (17). The columns are bridged inferiorly by the ischiopubic ramus, which is composed of the inferior pubic ramus and the inferior ischial ramus (15).

Patients with Acetabular Fracture

Acetabular fractures are uncommon, with a reported frequency of three fractures per 100,000 trauma patients (18). Acetabular fractures result from either high-energy trauma or low-energy trauma in the elderly, with one meta-analysis reporting that 80.5% of acetabular fractures result from motor vehicle accidents and 10.7% result from falls (19–21). Patients with high-energy acetabular fractures commonly have associated pelvic ring and lower extremity fractures. Life-threatening head, chest, and abdominal injuries are also associated with high-energy acetabular fractures (19,22). Bone fragments may penetrate into the bowel or genitourinary tract, converting these injuries to open fractures and increasing

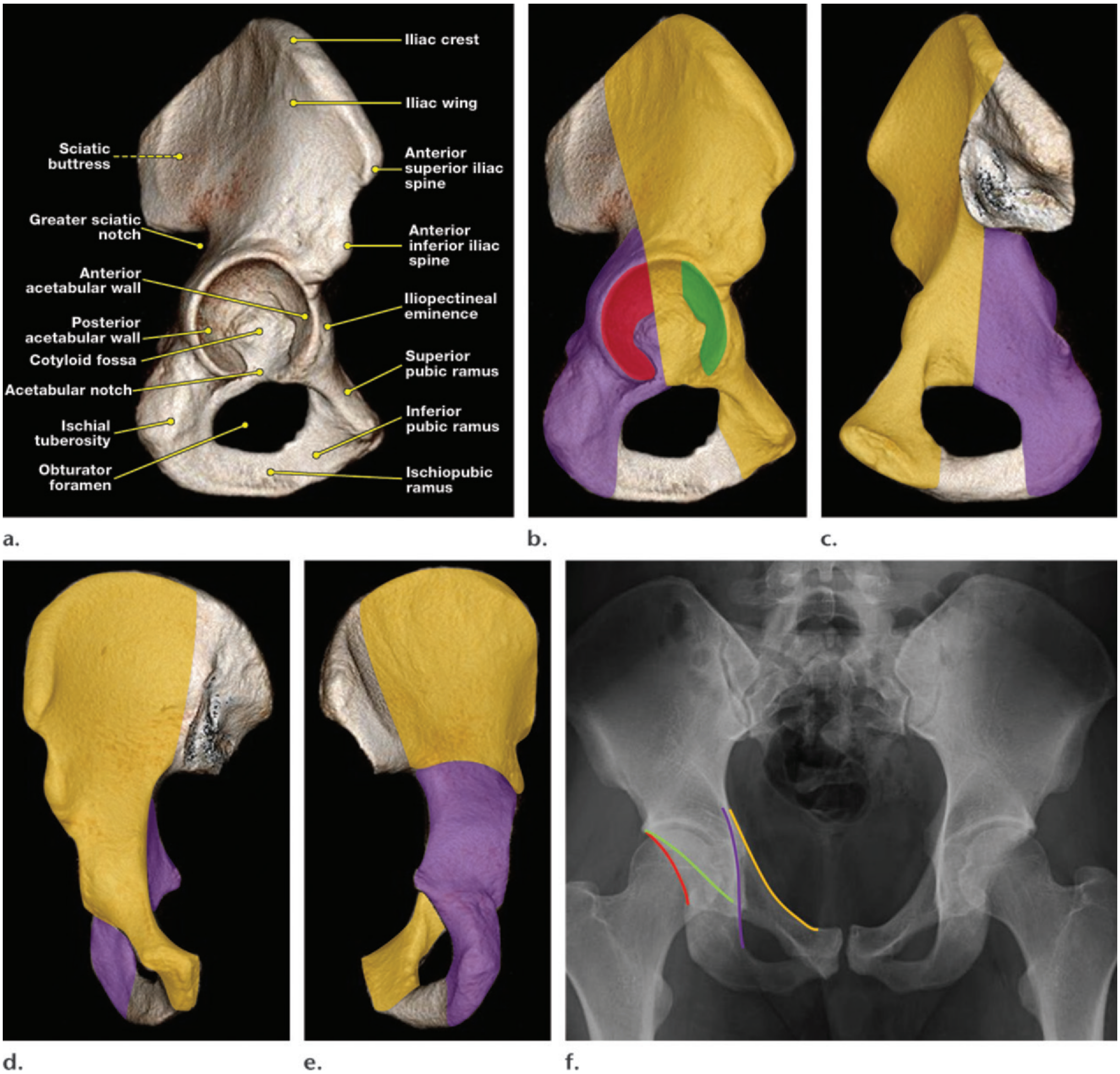


Figure 2. Acetabular anatomy. **(a)** Lateral surface-rendered 3D CT image shows the acetabulum. **(b–e)** Lateral **(b)**, medial **(c)**, anterior **(d)**, and posterior **(e)** 3D CT images show the anterior column (yellow area), anterior articular surface (green area), posterior column (purple area), and posterior articular surface (red area) of the acetabulum. **(f)** Frontal radiograph of the pelvis shows the iliopectineal line (yellow line), ilioischial line (purple line), anterior acetabular wall (green line), and posterior acetabular wall (red line).

the risk for infection and nonunion. An acetabular fracture is created when the femoral head and/or neck impact on the acetabulum. The exact type of acetabular fracture depends on the position of the hip during the trauma, the direction and magnitude of the impact force, and the quality of bone (23).

Acetabular fractures among elderly patients are increasing, with recent data indicating that nearly one-quarter of acetabular fractures occur in patients who are older than 60 years of age (24–26). In this patient population, the most common fracture mechanism is falling onto the greater trochanter, which drives the femoral head anteromedially into the acetabulum, causing anterior column fracture or anterior column with posterior hemitransverse fracture, with associated medial displacement of the quadrilateral plate and damage to the articular cartilage of the femoral head (24,27).

Systems of Acetabular Fracture Classification

There are two primary purposes for classifying acetabular fractures: *(a)* to communicate the type of fracture in an individual patient for purposes of treatment and *(b)* to categorize the fracture for purposes of research and to investigate outcomes. There are two classic morphologic classification systems for acetabular fractures: the Judet and Letournel system (4) and the Orthopedic Trauma Association (OTA)/Ar-

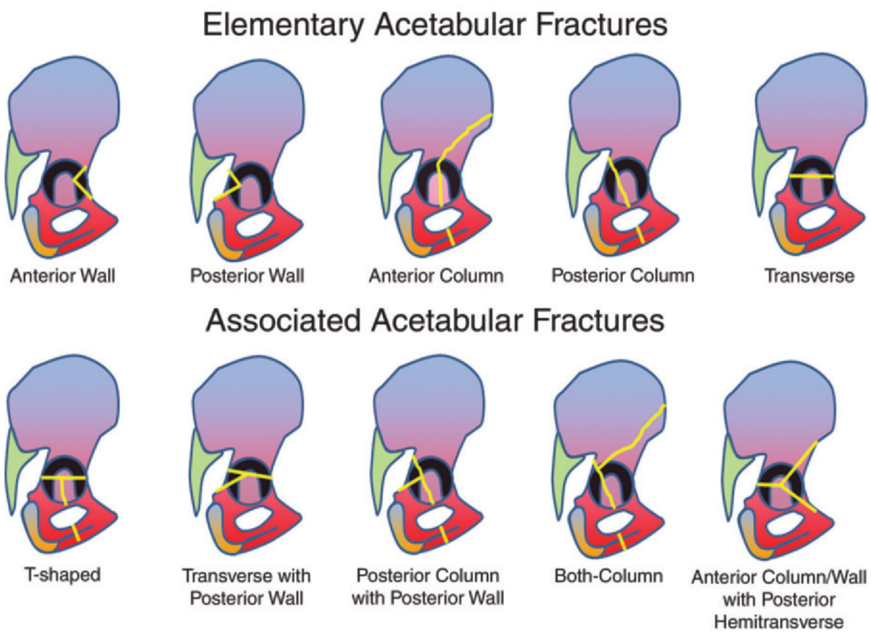


Figure 3. Diagrams show the 10 types of fracture in the Judet and Letournel acetabular fracture classification system. Green sacrum = posterior aspect.

beitsgemeinschaft für Osteosynthesefragen (AO) scheme (28), as well as a more recent classification system proposed by Harris et al (29,30). The Judet and Letournel classification system divides acetabular fractures into five elementary (or elemental) and five associated fractures, for a total of 10 fracture types. The Judet and Letournel classification system is most commonly used by orthopedic surgeons and radiologists. The OTA/AO scheme uses the definitions put forth by Judet and Letournel but organizes fractures differently, with nine primary fracture configurations and many subcategories and modifiers. This system is predominantly used for research purposes; however, it is also used for surgical billing and coding at some centers. The Harris system was more recently proposed (during the CT era) as a way of classifying the large number of fracture variants into four categories. It has not displaced the Judet and Letournel system.

The Judet and Letournel Classification of Acetabular Fractures

In 1964, Judet et al (4,31,32) introduced, and later slightly modified, a classification scheme for acetabular fractures that is still in use today. Before this time, acetabular fractures were poorly understood and inappropriately treated with nonstandardized methods (30). Judet and Letournel introduced the concept of radiographic analysis of lines formed by cortical surfaces parallel to the x-ray beam on anterior-to-posterior and 45° oblique pelvic radiographs to anatomically classify acetabular fractures. This classification was used, in turn, to determine the most appropriate treatment. The four lines that are fundamental to Judet and Letournel's approach are the anterior and posterior acetabular rims (or walls) and the iliopectineal and ilioischial lines (Fig 2).

In the Judet and Letournel system, there are 10 fractures or fracture combinations that separate walls from the acetabulum and columns from the sciatic buttress or that are transversely oriented through the acetabulum (Fig 3). Fractures are classified into five elementary fractures, which divide the innominate bone and acetabulum into two major fragments, and five associated fractures, which divide the innominate bone and acetabulum into three major fragments. Naturally, real fractures may "break the rules" and divide the innominate bone into more than three fragments (5). The five elementary fracture types are posterior wall, anterior wall, posterior column, anterior column, and transverse. The five associated fracture types are combinations or partial combinations of the elementary fractures and include transverse with posterior wall, posterior column with posterior wall, T-shaped, anterior column or wall with posterior hemitransverse, and associated both column. In general, column fractures divide the acetabulum into anterior and posterior parts, whereas transverse fractures divide it into superior and inferior parts (5,7). Although some fracture patterns are not directly accounted for in this scheme, many are subsumed into these 10 categories (based on Letournel's original work).

Despite the presence of 10 fracture types, five fractures (posterior wall, transverse, transverse with posterior wall, both column, and T-shaped) account for approximately 80% of all acetabular fractures (2,3,19). Giannoudis et al (19) compiled

Table 1: Distribution of Judet and Letournel Acetabular Fracture Categories in Studies by Giannoudis et al and by Geijer and El-Khoury

	Distribution (%)	
Fractures by Category	Giannoudis et al	Geijer and El-Khoury
High frequency		
Posterior wall	23.6	18.3
Both column	21.7	27.0
Transverse and posterior wall	17.4	22.5
Intermediate frequency		
T-shaped	9.3	7.7
Transverse	8.3	4.7
Posterior column and posterior wall	5.7	5.3
Anterior wall or column and posterior hemitransverse	5.0	7.1
Low frequency		
Anterior column	3.9	3.9
Posterior column	3.5	2.5
Anterior wall	1.7	1.3
Posterior wall component*	46.7	46.1

Sources.—References 2 and 19.
*The percentage of fractures with a posterior wall component.

acetabular fracture frequencies from 34 series, and Geijer and El-Khoury (2) compiled acetabular fracture frequencies from five series (Table 1). Frequencies are slightly different between the studies, but the categories of high, intermediate, and low frequency are the same (Table 1). For example, the three most common fracture types are posterior wall, transverse with posterior wall, and associated both column, which together account for approximately two-thirds of all fractures. Fractures that contain a posterior wall component are most common, with nearly one-half of all acetabular fractures containing a posterior wall component.

The Judet and Letournel classification system is the most widely used system and is considered the most useful by surgeons (17). Still, various issues have been raised. Some rare fractures are not classifiable with this system (2). It may be considered incomplete because factors that are important surgically, such as the presence of intra-articular fragments or a femoral head fracture, the number and size of posterior wall fragments, and articular impaction and rotation of fragments, are not included. Its nomenclature is asymmetric; for example, anterior and posterior wall fractures are dissimilar, because a posterior wall fracture includes only wall fragments, whereas anterior wall fractures also include a portion of the column. Reproducibility of classification is also an issue. In one study, although there was high accuracy among orthopedic surgeons (with some specializing in acetabular fracture surgery) for certain fractures with radiographs and axial CT images (eg, transverse, 99% and posterior wall, 94%), there was low accuracy for other types of fractures (eg, T-shaped, 49%; anterior wall, 52%; and anterior wall or column with posterior hemitransverse, 54%) (33).

There are 10 acetabular fracture types in the Judet and Letournel classification system. In describing these fracture types, we focus on their appearance on surface-rendered 3D images. Patients are imaged with CT in the axial plane, with thin-section images (0.5–0.625-mm) generated for 3D reconstruction. Three-dimensional visualization software packages initially generate images in the anatomic orientation in which the patient was imaged. However, acetabular fractures, by convention, are still described and illustrated looking at the acetabulum en face from the lateral side, with the acetabular notch pointing downward such that the articular surface of the acetabulum appears as an inverted "U" (Fig 2, Movie 1). This practice has important implications for how fractures appear and are described with axial and surface-rendered 3D CT images (Fig 4).

Posterior Wall

Posterior wall fractures involve the posterior acetabular rim, which includes the posterior articular surface (Fig 5, Movie 2). Because a

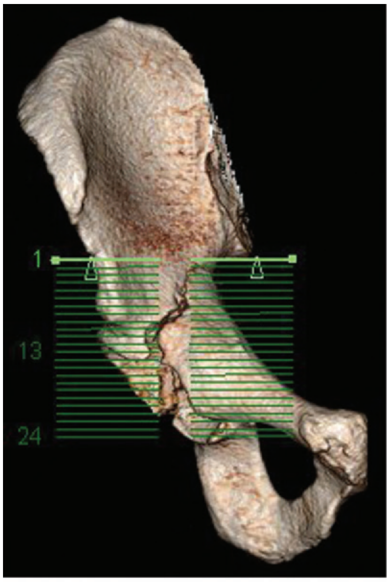
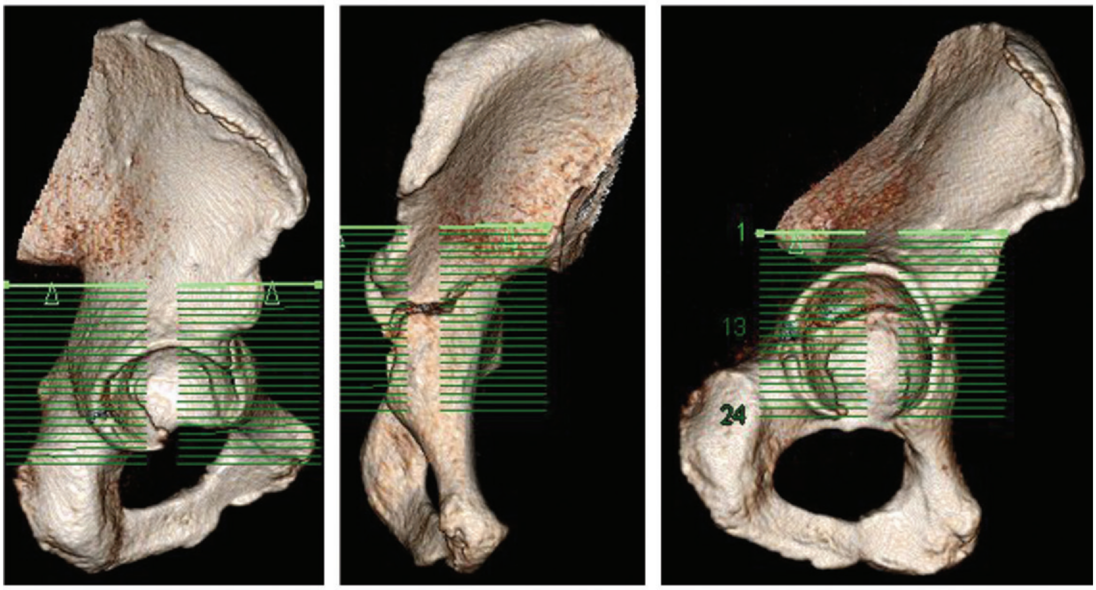


Figure 4. Anatomic and acetabular positioning of the hemipelvis. **(a, b)** Frontal **(a)** and lateral **(b)** 3D surface-rendered CT images show the acetabulum in anatomic position. The overlay grid shows how images obtained in the axial plane make the transverse fracture appear sagittally oriented. **(c, d)** Frontal **(c)** and lateral **(d)** 3D surface-rendered CT images show the acetabulum, which is positioned such that on the lateral view, the acetabular cup is viewed en face with the acetabular notch directed inferiorly. In this position, the transverse fracture is oriented more closely to the horizontal lines of the overlay grid.

a.



b. c. d.

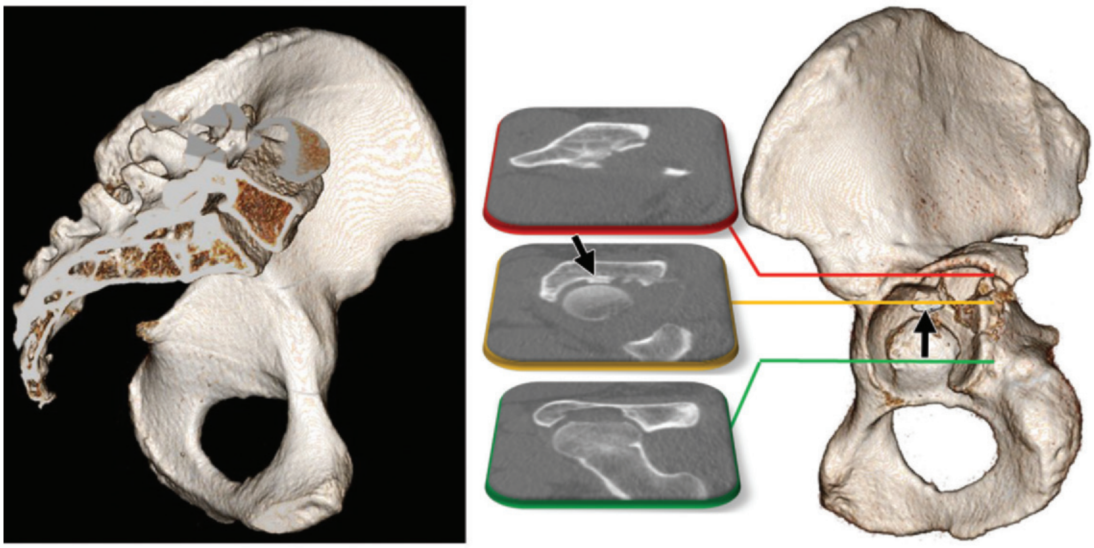
posterior wall fracture involves only the posterior articular surface, it is not seen on the medial acetabular surface (4). The fracture may separate one or multiple fragments, with comminution having implications for prognosis. The most common fracture mechanism is trauma to the distal femur or knee with the hip flexed (eg, the knee striking the dashboard of a car during a head-on collision), which drives the femoral head posteriorly into the posterior acetabular wall and causes posterior wall fracture and posterior hip dislocation. Greater hip abduction may result in a larger posterior wall fracture fragment (32). During posterior dislocation, wall fragments may also be driven into the underlying bone, an injury referred to as marginal impaction, which adversely affects restoration of acetabular joint congruity. These bone fragments must be elevated and buttressed into place for successful restoration of joint congruity. Posterior wall fractures may extend superiorly to involve the weight-bearing dome (34). Rarely, a pure superior rim fracture may occur. Pure superior rim fractures are superior to the arcuate line medially and thus spare the quadrilateral plate (4,35). They are classified as posterior wall fractures in the writings of Letournel (4). On axial CT images, the posterior wall fracture line is oblique to the coronal and sagittal planes.

Posterior Column

Posterior column fractures involve the posterior portion of the acetabulum, disconnecting it from the sciatic buttress (Fig 6, Movie 3). The fracture

RadioGraphics

a.



b. c.

Figure 5. Posterior wall acetabular fracture in a 45-year-old man. **(a)** Lateral 3D surface-rendered CT image of the acetabulum shows a comminuted posterior wall fracture (arrow). **(b)** Medial 3D surface-rendered CT image of the acetabulum shows the quadrilateral plate to be intact. **(c)** Composite image that correlates 3D surface-rendered images with axial images and is constructed relative to the acetabular orientation shows that, on the superior image (red outline), which is obtained at the level of the acetabular roof, the fracture is obliquely oriented, a finding typical of a posterior wall fracture. An impacted fragment and a free fragment are also seen. On the middle image (yellow outline), a loose body (arrows) is seen within the joint. The inferior part of the posterior wall is intact, as is seen on the inferior image (green outline).

runs from the greater sciatic notch through the acetabulum and the obturator foramen and into the ischiopubic ramus. Alternatively, the fracture line may run posterior to the obturator foramen and split the ischial tuberosity, creating an intermediate fracture type between a wall fracture and a typical posterior column fracture (5,13,17). Posterior column fractures are very unstable, and the femoral head may be dislocated or subluxated. Traction may be necessary to maintain the position of the femoral head before definitive posterior column fixation. The superior gluteal neurovascular bundle, which runs in the greater sciatic notch, may also be trapped under the posterior column fragment and must be mobilized before fixation. On axial CT images, the dominant fracture line at the level of the acetabular roof is in the coronal plane.

Anterior Column

Anterior column fractures involve the anterior column, including the anterior portion of the acetabulum, which is disconnected from the sciatic buttress (Fig 7, Movie 4) (32). The superior extent of the fracture may be high (through the iliac crest), intermediate (between the anterior iliac spines), low (in the iliopsoas groove, just below the anterior inferior iliac spine), or very low (at the iliopectineal eminence) (4,23). The fracture then crosses the obturator foramen, a feature that differentiates it from an anterior wall fracture. Anterior column fractures are associated with anterior hip dislocation and are common in elderly patients (4). Anterior column fractures carry a better prognosis than do posterior column fractures (36). On axial CT images, the dominant fracture line at the level of the acetabular roof is in the coronal plane.

a. b.

Figure 6. Posterior column acetabular fracture in a 45-year-old man. Lateral **(a)** and medial **(b)** 3D surface-rendered CT images of the acetabulum show a markedly displaced fracture separating the posterior column (*) from the sciatic buttress. As with other column fractures, a fracture (arrow) runs through the ischiopubic ramus. A mild step artifact is also seen, a result of the use of 2.5-mm source images for 3D surface rendering.

Anterior Wall

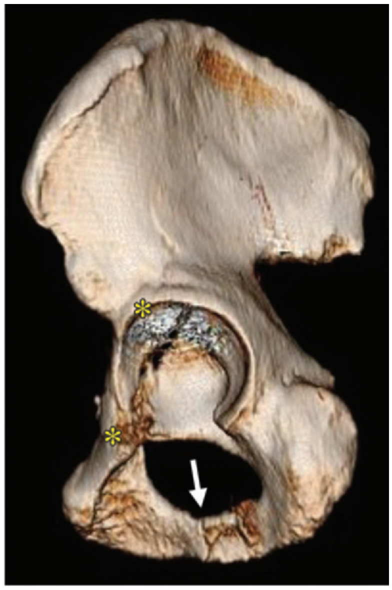
There is much confusion regarding what constitutes an anterior wall fracture; therefore, clear communication is necessary to ensure a correct treatment plan (35,37). Fractures that involve the anterior acetabular rim without extending to the quadrilateral surface have been described in the literature but are not considered anterior wall fractures by Judet and Letournel (Fig 8) (35,37). According to Letournel (4), an anterior wall fracture also contains the portion of the anterior column anterior to the acetabulum (ie, extension through the quadrilateral surface) but is different from anterior column fractures in that it leaves a large portion of the anterior column connected to the sciatic buttress (Fig 9, Movie 5) (32). This definition is also used by the OTA classification (28). There is ambiguity in AO classification illustrations as to whether the anterior column is involved in an anterior wall fracture; however, the AO classification text appears to use the Judet and Letournel definition, which includes a portion of the anterior column (38,39). In clear contradistinction to the Judet and Letournel scheme, the Harris system explicitly defines the anterior wall as being just the rim, a classification that has been advocated by others (Fig 8) (30,37).

Anterior wall fractures are the least common type of acetabular fracture. They are associated with anterior dislocation of the hip while the hip is in abduction and external rotation and are seen in elderly patients. Aside from the considerations that were already mentioned, anterior wall fractures do not involve the obturator foramen, whereas anterior column fractures do. In differentiating anterior wall and superior pubic ramus fractures, anterior wall fractures liberate a bone fragment involving the lateral aspect of the superior pubic ramus and more posteriorly along the pelvic brim (5). Combination anterior wall and anterior column fractures are categorized by Letournel (4) as anterior wall fractures.

Transverse

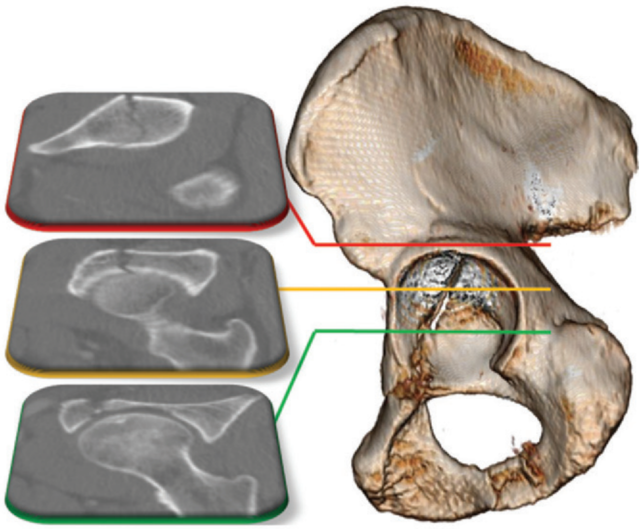
Transverse acetabular fractures divide the acetabulum into superior (ie, iliac) and inferior (ie, ischiopubic) fragments (Fig 10, Movie 6). The fracture line involves both columns, but a portion of each column remains connected to the sciatic buttress, a characteristic that differentiates a transverse fracture pattern from an associated both-column fracture pattern. The transverse nature of the fracture is best appreciated on the medial aspect (ie, the quadrilateral plate) of surface-rendered 3D images (40). There are three categories of transverse acetabular fractures (Fig 10) (4,5). Transtectal fractures traverse the weight-bearing acetabular dome. As a result, the fracture fragment and femoral head are displaced medially. Juxtatectal

Figure 7. Anterior column acetabular fracture in a 63-year-old man. **(a, b)** Lateral **(a)** and medial **(b)** 3D surface-rendered CT images of the acetabulum show a fracture of the anterior column that extends from the iliac wing (best seen in **b**) through the superior portion of the acetabulum, with separation of the anterior column (*) from the sciatic buttress. A fracture line also extends through the ischiopubic ramus (arrow in **a**). **(c)** Composite image that correlates 3D surface-rendered images with axial images and constructed relative to the acetabular orientation shows that, on the superior image (red outline), which is obtained at the level of the acetabular roof, the fracture is coronally oriented, a finding typical of column fractures. On the middle image (yellow outline), the fracture crosses the superior articular surface. On the inferior image (green outline), the fracture line involves the anterior articular surface–cotyloid fossa junction. If this inferior image is viewed in isolation, it may appear as an anterior wall fracture, but the 3D surface-rendered image, or the summation of axial images, confirms that it is an anterior column fracture.



a.

b.



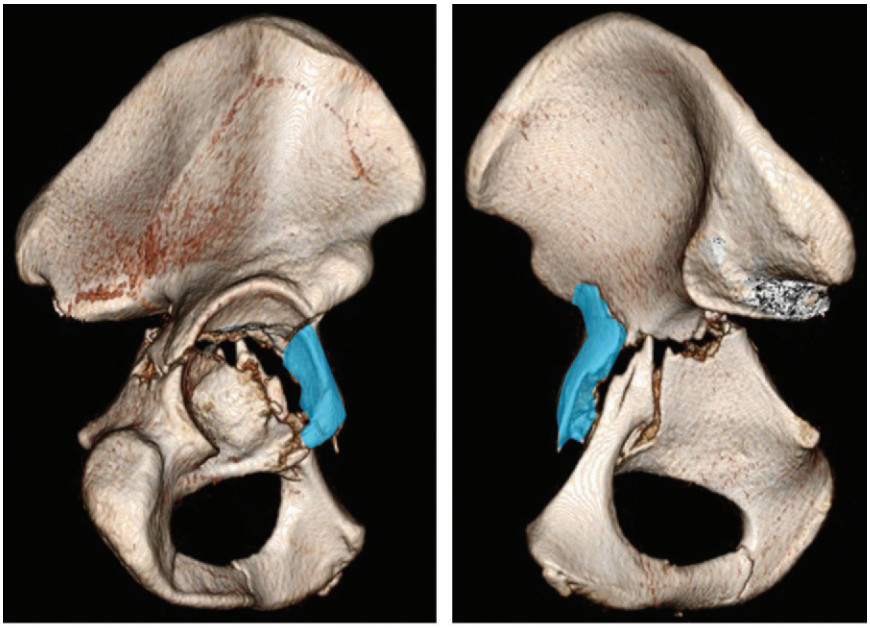
c.

fractures traverse just below the weight-bearing acetabular dome, at the junction of the articular surface and the cotyloid fossa. Infratectal fractures traverse the cotyloid fossa and the anterior and posterior horns of the acetabular articular surface. With infratectal fractures, the femoral head remains with the weight-bearing acetabular dome and does not displace medially (5). There is a spectrum of obliquity between the axial and sagittal planes such that, as the fracture becomes more cranial on the acetabular articular surface, it becomes more sagittally oriented, thereby separating a larger portion of the articular surface from the acetabular roof (4,23). Although a transverse acetabular fracture is "transverse," on axial CT images the fracture line is in the sagittal plane, typically crossing from medial to lateral as one scrolls through images from cranial to caudal (32). This occurs because the acetabulum is imaged anatomically, and it is classically described with the acetabulum facing laterally and the acetabular notch facing inferiorly (Fig 4). When the most lateral extent of the fracture is viewed on axial CT images, it may appear as distinct anterior and posterior wall fractures (Fig 11). Therefore, 3D images must be constructed, or axial images must be summated in one's mind while scrolling through a series of axial images, to appreciate the true transverse nature of this fracture pattern.

Transverse with Posterior Wall

The transverse with posterior wall fracture is a common associated fracture (Fig 12, Movie 7). A rare variant of this pattern is a T-shaped fracture with an additional posterior wall fracture. This variant has the worst prognosis of all acetabular fractures (4,23).

Figure 8. Harris-type anterior wall acetabular fracture in a 37-year-old woman. Lateral 3D surface-rendered CT image shows a fracture (arrow) involving the anterior acetabular rim (*) with no involvement of the anterior column. The granular appearance is a result of use of bone-kernel reconstruction source axial images.



a. b.

Figure 9. T-shaped acetabular fracture with an additional Judet and Letournel–type anterior wall fracture. Lateral **(a)** and medial **(b)** 3D surface-rendered CT images show a T-shaped fracture with an additional anterior wall component (blue area). The anterior wall fracture is also seen on the medial side, as the Judet and Letournel definition of anterior wall fractures describes.

T-shaped

T-shaped fractures are transverse fractures with an inferiorly directed stem, which may run vertically through the inferior pubic ramus or through the ischium (Fig 13, Movie 8) (4). Accurate diagnosis of T-shaped fractures is essential because a more extensive surgical exposure may be required to repair them. Despite the need for accurate diagnosis, one study (which used radiographs and axial CT images) showed that diagnostic accuracy for T-shaped fractures is the lowest of all types of acetabular fractures (4,33). The posterior component is usually more displaced than the anterior component, so a posterior surgical approach to the acetabulum is generally indicated (32). Still, a combination of approaches may be necessary because fixation of either the anterior or posterior component alone does not address the fixation of the other component (15). Posterior column with anterior hemitransverse fractures and transverse with anterior wall fractures are considered T-shaped fractures (41).

Figure 10. Transverse acetabular fracture in a 63-year-old man. **(a)** Lateral 3D surface-rendered CT image shows a transverse fracture extending across the acetabulum (arrows). **(b)** Medial 3D surface-rendered CT image shows the fracture extending across the quadrilateral plate (arrows). **(c)** Lateral 3D surface-rendered CT image shows the transtectal (red line, *T*), juxtatectal (yellow line, *J*), and infratectal (blue line, *I*) levels.

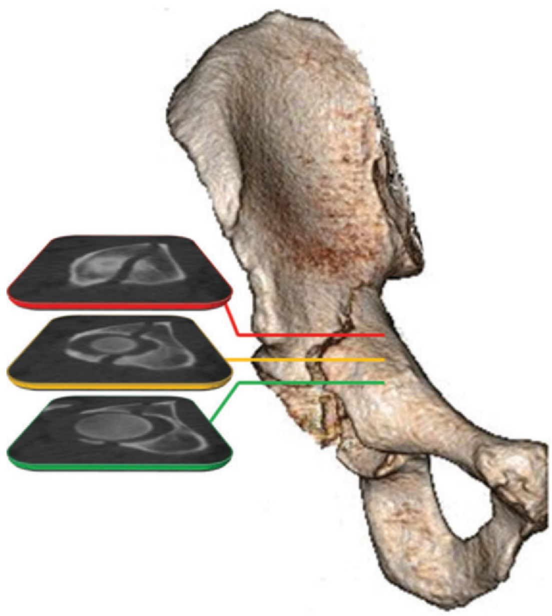


Figure 11. Composite image that correlates a 3D reconstruction of the acetabulum in its anatomic position with axial CT images. The superior axial image (red outline), which was obtained at the level of the acetabular roof, shows a fracture in a near sagittal plane. The middle (yellow outline) and lower (green outline) axial images, which were obtained at the level of the superior acetabulum, show fractures through the anterior and posterior acetabular rims. When correlated with the 3D image (or a series of axial images), it is clear that, rather than representing anterior and/or posterior wall fractures, the fracture lines are components of a single transtectal transverse acetabular fracture.

Associated Both-Column

Associated both-column fractures are unique in that the entire weight-bearing portion of the acetabulum is disconnected from the sciatic buttress (Fig 14, Movie 9). The two columns are separated from each other, with the two dominant fractures nearly perpendicular to each other (13). Because of the traumatic impact, there are usually additional fracture lines in addition to the dominant lines that separate the anterior and posterior columns (23). The femoral head always displaces medially (4). On the obturator oblique radiograph, the "spur sign" may be seen as a shard of bone superior to the femoral neck, if there is a laterally projecting spur of sciatic buttress bone remaining attached to the sacroiliac joint and medial displacement of the remainder of the acetabulum (4,7). An equivalent characteristic bone fragment may also be identified on CT images (5). Both columns are free to rotate in an associated both-column acetabular fracture, and the two columns may remain congruent to the femoral head, a finding that is called secondary congruence and is the foundation of nonoperative treatment of associated both-column fractures. An acetabulum with secondary congruence may still be medially displaced, and the limb may be shortened because of the new location and orientation of the acetabulum (23).

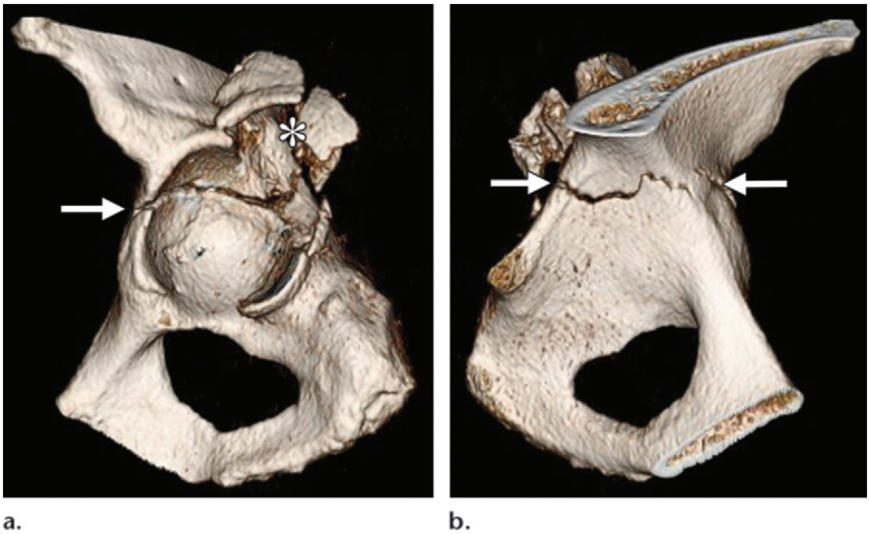


Figure 12. Transverse with posterior wall acetabular fracture in a 54-year-old woman. Lateral **(a)** and medial **(b)** 3D surface-rendered CT images show a transverse acetabular fracture (arrows). A displaced comminuted posterior wall fracture (* in **a**) is also seen.

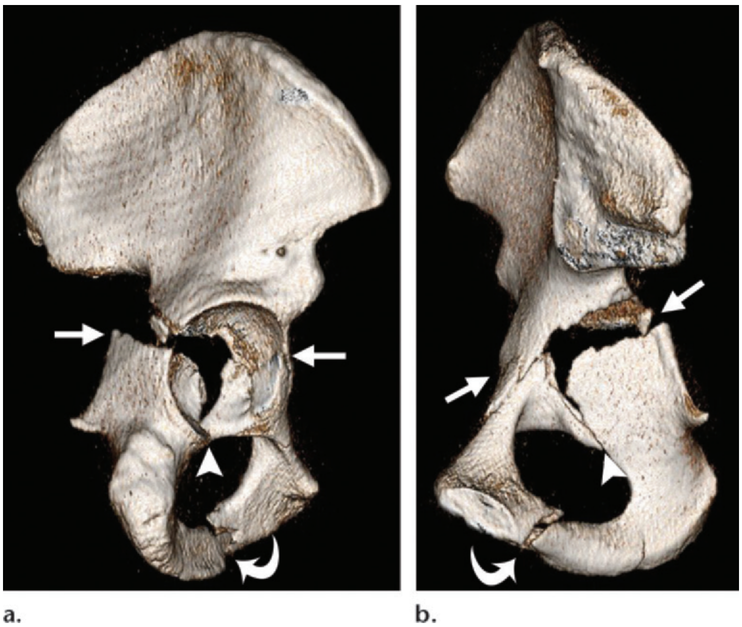


Figure 13. T-shaped acetabular fracture in a 40-year-old man. Lateral **(a)** and medial **(b)** 3D surface-rendered CT images show a transverse acetabular fracture (straight arrows), the anterior portion of which is nondisplaced. The stem of the T-shaped fracture (arrowhead) extends inferiorly through the acetabular notch and the ischiopubic ramus (curved arrow).

Anterior Column or Wall with Posterior Hemitransverse

The anterior component of anterior with posterior hemitransverse fractures may be an anterior wall or an anterior column fracture (Fig 15; Movies 10, 11) (4,17). A low or very low anterior column fracture with a posterior hemitransverse fracture is similar to a T-shaped fracture; however, the anterior component rises anteriorly in an anterior column with posterior hemitransverse fracture, whereas that in a T-shaped fracture continues straight across. Similar to elementary transverse fractures, the posterior hemitransverse component may occur at various levels. The anterior component is usually more displaced than the posterior component; thus, an anterior approach for repair is generally indicated (32). The anterior column or wall with posterior hemitransverse fracture is a common fracture pattern in elderly patients.

Posterior Column with Posterior Wall

Posterior column and wall fractures may occur concurrently (Fig 16, Movie 12). The column component may be nondisplaced and therefore can be hard to detect. The posterior wall fragments may be comminuted and/or impacted, similar to in an elementary fracture.

OTA/AO Classification of Acetabular Fractures

The OTA/AO classification system was developed on the basis of the names given by Judet and Letournel. Instead of dividing fractures into 10 categories, it divides them into three categories (group A, single-wall or -column fractures;

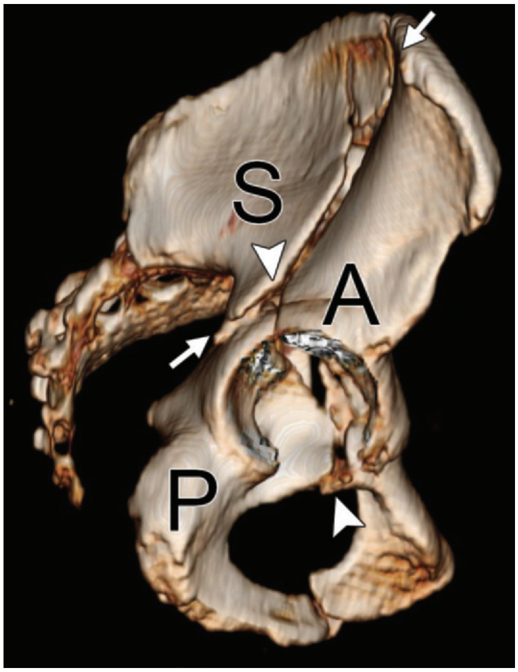


Figure 14. Associated both-column acetabular fracture in a 54-year-old man. Lateral surface-rendered CT image shows two dominant fracture lines, one of which separates the posterior column *(P)* from the sciatic buttress *(S)* (arrowheads) and the other of which extends through the iliac wing, separating the anterior column *(A)* from the sciatic buttress (arrows). In this fracture, the acetabulum is completely dissociated from the sciatic buttress.

group B, transverse fractures or transverse fracture variants; and group C, both-column fractures), each of which includes three subcategories (1, 2, and 3), for a total of nine major categories. Each subcategory has three additional subcategories (1, 2, and 3) that follow a decimal point (28). The system also incorporates qualifiers in the form of Greek letters, as well as lowercase letters with numeric superscripts, to describe factors such as femoral head dislocation or subluxation, damage to the acetabular or femoral head articular cartilage, intraarticular fragments, and the degree of comminution (28). The complexity of this system makes it well suited for research purposes; however, it is also useful for surgical procedure coding and billing.

Harris Classification of Acetabular Fractures

The Harris classification scheme is a CT-based scheme in which the anterior and posterior lips of the acetabulum are defined as walls, and the more medial portions of the acetabulum, including the quadrilateral plate, are considered the columns (29). This is an important difference from the Judet and Letournel classification, in which anterior wall fractures also encompass a portion of the column. Furthermore, Harris shortens the anterior column such that its superior or ventral extent reaches only to the iliopectineal line and pelvic brim, similar to the superior or ventral extent of the posterior column (which Harris defines as the arcuate line) (29). With these definitions, fractures are divided into four categories. Category 0 fractures are anterior wall or posterior wall only fractures. Category 1 fractures are single-column fractures. Category 2 fractures involve both columns (ie, transverse, hemitransverse, or fracture variants), with subcategories for fracture line extension (A = no extension, B = superior extension, C = inferior extension, and D = superior and inferior extension). In category 3 fractures (ie, associated both-column fractures), the acetabulum is dissociated from the axial skeleton. Although the Harris classification system is able to classify more types of fractures and introduces more symmetry between the anterior and posterior walls and columns, it has not displaced the Judet and Letournel classification system, likely because of the applicability of the Judet and Letournel classification system to both CT and pelvic radiograpy (42).

Imaging Acetabular Fractures

The goal of acetabular imaging is to depict the fracture and provide necessary information to the surgeon, who ultimately determines whether surgical repair is indicated and how it should be performed (42). In trauma patients, initial imaging of the acetabulum is usually performed with a portable anterior-to-posterior pelvic radiography unit in the trauma bay of the emergency department. Although it is helpful in initial triage, these images are commonly limited by the portable technique, suboptimal positioning, and obscuration by over- and underlying material (43). There are four cardinal lines that should be identified bilaterally: *(a)* the anterior acetabular wall, which is identified by following the anteroinferior portion of the superior pubic ramus

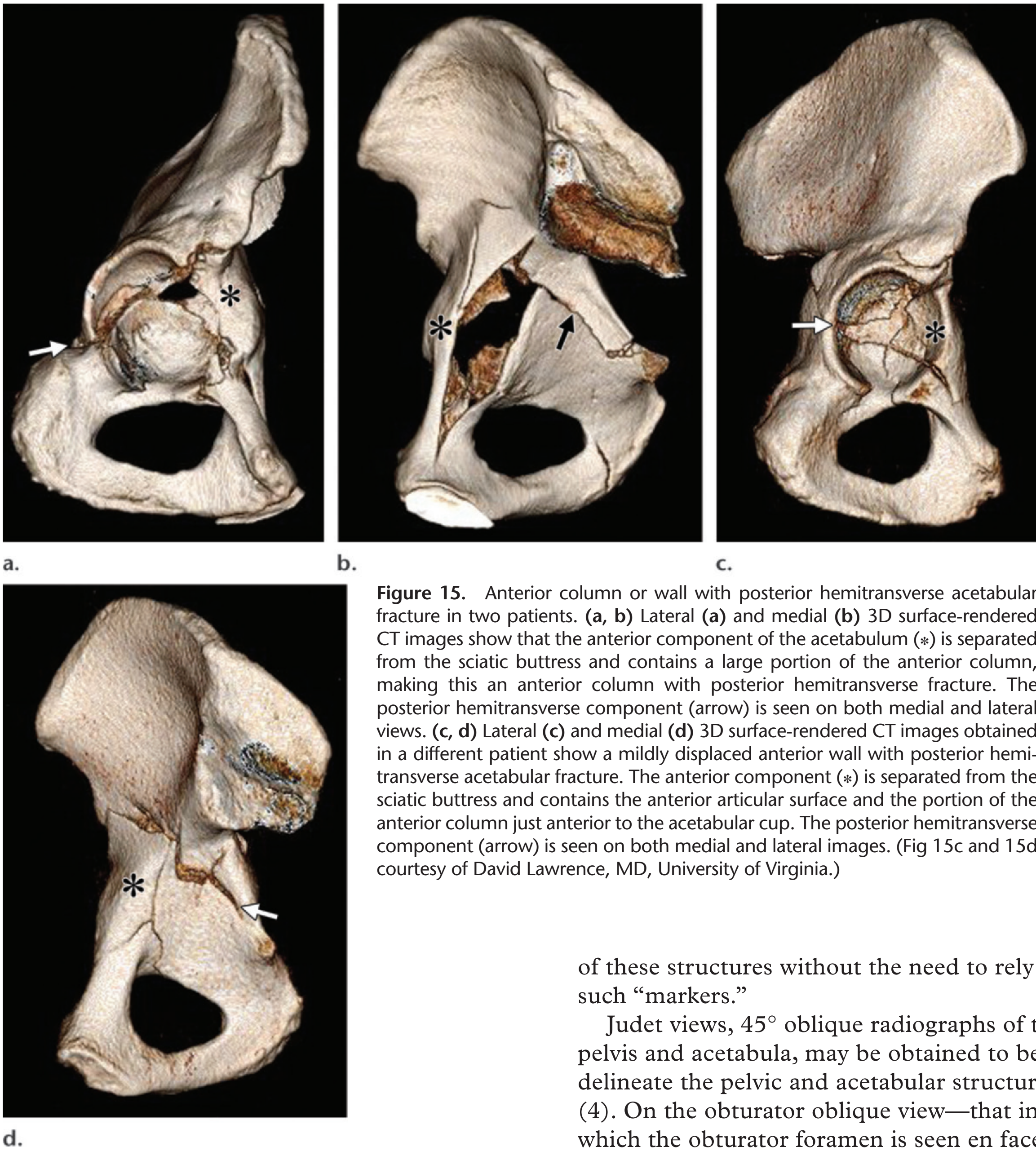


Figure 15. Anterior column or wall with posterior hemitransverse acetabular fracture in two patients. **(a, b)** Lateral **(a)** and medial **(b)** 3D surface-rendered CT images show that the anterior component of the acetabulum (*) is separated from the sciatic buttress and contains a large portion of the anterior column, making this an anterior column with posterior hemitransverse fracture. The posterior hemitransverse component (arrow) is seen on both medial and lateral views. **(c, d)** Lateral **(c)** and medial **(d)** 3D surface-rendered CT images obtained in a different patient show a mildly displaced anterior wall with posterior hemitransverse acetabular fracture. The anterior component (*) is separated from the sciatic buttress and contains the anterior articular surface and the portion of the anterior column just anterior to the acetabular cup. The posterior hemitransverse component (arrow) is seen on both medial and lateral images. (Fig 15c and 15d courtesy of David Lawrence, MD, University of Virginia.)

superolaterally; *(b)* the posterior acetabular wall, which projects more laterally than the anterior wall and is identified by following the lateral ischium superolaterally; *(c)* the iliopubic (ie, iliopectineal) line, which is a marker of the anterior column and is a continuation of the pelvic brim onto the anterior-superior aspect of the superior pubic ramus; and *(d)* the ilioischial line, which is a marker of the posterior column and is formed by the cortex of the posterior quadrilateral plate (which is identified by following the medial ischium superiorly) (Fig 2) (4,17,23). Analysis of these lines allows sequential deduction of which portions of the acetabulum are fractured and which are intact. However, the use of MDCT allows direct and complete evaluation of these structures without the need to rely on such "markers."

Judet views, 45° oblique radiographs of the pelvis and acetabula, may be obtained to better delineate the pelvic and acetabular structures (4). On the obturator oblique view—that in which the obturator foramen is seen en face—the anterior column, posterior acetabular wall, and obturator foramen are accentuated. The spur sign of the associated both-column acetabular fracture is best visualized on the obturator oblique view. On the iliac oblique view—that in which the iliac wing is seen en face—the posterior column, anterior acetabular wall, iliac wing, and greater sciatic notch are accentuated (7,17). Aside from the utility of these views to depict and characterize acetabular fractures, they are also used intraoperatively to evaluate the quality of acetabular fracture reduction (5). Because rotating a patient may be painful, especially onto the side with the fracture, and carries a risk of displacing or further displacing the fracture, an angiography C-arm may be used to obtain Judet views without moving the patient (42,44). Alternatively, MDCT data can be postprocessed

a. b.

Figure 16. Posterior column with posterior wall fracture in a 59-year-old man. Lateral **(a)** and medial **(b)** 3D surface-rendered CT images show separation of the posterior column *(P)*, a finding seen on both medial and lateral images. A displaced comminuted posterior wall fracture is also seen on the lateral image (* in a).

into thick multiplanar reformatted images to appear as planar Judet views (45). In general, these thick multiplanar reformatted images depict the necessary anatomy, but they have lower spatial resolution and therefore lack the crispness of true radiographs.

Now that panscanning with MDCT is commonly performed in trauma patients, high-quality thin-section axial CT images are commonly obtained. These images can then be reformatted into coronal and sagittal images, as well as surface-rendered 3D images. Although pelvic CT has a seemingly higher radiation dose compared with radiography, one study reported that a five-view pelvic radiography series (5.0 mSv) had a higher effective dose to the patient than did pelvic CT (4.4 mSv) (46). Furthermore, fractures are directly seen on CT images rather than inferred from interruption of the four cardinal lines. This is particularly important for minimally displaced fractures, complex fracture patterns, and small intra-articular fracture fragments (41). CT is more sensitive and accurate for depicting fractures than is radiography with anteroposterior (AP) and Judet views (47). It also depicts soft-tissue complications, such as involvement of the sciatic nerve and the superior and inferior gluteal arteries. CT is essential for identifying gastrointestinal or genitourinary tract injuries, because they may increase the risk for postoperative wound infection, which hampers postoperative bone and wound healing and may lead to destruction of articular cartilage (41). Morel-Lavallée lesions, closed degloving injuries in which the skin and subcutaneous tissue overlying the greater trochanter are stripped from the underlying fascia, may also be detected with CT (or magnetic resonance [MR] imaging). These lesions may become superinfected and complicate recovery (48,49).

We have found that thin-section MDCT images reformatted into surface-rendered 3D images are extremely helpful for visualizing, describing, and communicating acetabular fracture geometry. We include videos that describe how this can be accomplished with TeraRecon (TeraRecon, San Mateo, Calif), but similar functionality is available with other 3D advanced visualization packages (Movies 13, 14). Thin-section (preferably 0.5–0.625-mm) axial soft-tissue–kernel images should be used to minimize artifacts from surrounding soft tissues. (Consider the artifact present in Fig 8, for which only thin axial bone-kernel images were available.) Virtually disarticulating the femur from the acetabulum; removing oral, rectal, or intravenous contrast material–opacified structures; and removing the contralateral hemipelvis may help visualize the major fracture lines (2,7).

Strengths and weaknesses of radiography, standard planar CT, and surface-rendered 3D MDCT are delineated in Table 2 (15,17,40,47,50–54). Regarding 3D images, one study showed that at all levels of training among orthopedic surgeons, there were benefits for the use of 3D images over that of axial CT images, with the greatest benefit among junior residents (55). Another study showed that although the use of 3D images did not significantly increase accuracy for radiologists, it did increase accuracy for orthopedic surgeons (56). We believe that use of surface-rendered 3D images could help address the low accuracy for

Table 2: Strengths and Weaknesses of Radiography, Planar CT, and Surface-rendered 3D MDCT

Modality	Strengths	Weaknesses
Radiography	Technically easy, quick, portable, not degraded by streak artifact	Findings may be obscured by overlying material, may be technically suboptimal because of patient condition and body habitus, not as sensitive as CT for depicting fractures
Planar CT	Depicts intraarticular fragments, articular impaction, soft-tissue injuries, subtle or nondisplaced fractures, and sacral and quadrilateral surface fractures	Requires summation of images in the mind (compared with 3D surface-rendered MDCT and radiography, which depict the entire acetabulum), fractures located exactly in the axial plane may be missed on axial images (but are well seen on sagittal and coronal reformatted images), streak artifact from orthopedic hardware or bullets may degrade images
3D surface-rendered MDCT	Display is easy to understand, depicts fractures well, has an interactive display (meaning that fractures can be viewed from multiple angles)	Subtle or nondisplaced fractures may be obscured from 3D image processing, images may be suboptimal in patients with osteopenia, images may be degraded by streak artifact from orthopedic hardware or bullets

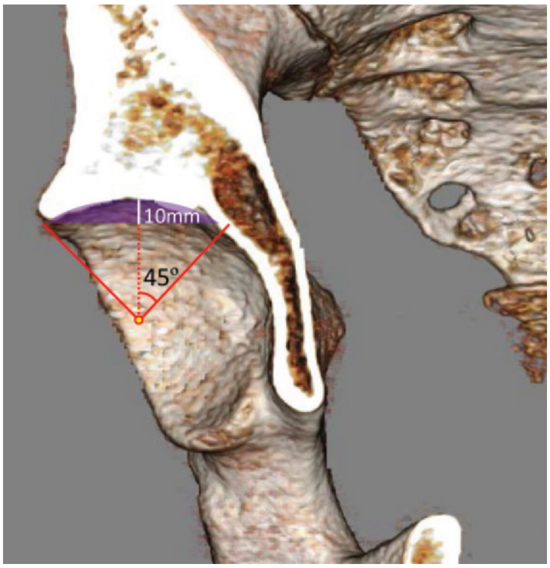


Figure 17. Roof arc angle and subchondral arc. Three-dimensional surface-rendered CT image of the right acetabulum, obtained in anatomic position with digital transection in the coronal plane, shows a 45° roof arc angle and a 10-mm subchondral arc (purple area), the superiormost 10 mm of the acetabulum and the arc subtended by the 45° roof arc angle. A fracture crossing the acetabular dome within 45° of the center is considered to involve the weight-bearing dome.

complex fracture classification that was reported by Beaulé et al (33) when using radiographs and axial images alone. Indeed, in our experience, the addition of 3D images aids understanding of complex acetabular fractures and allows clearer communication of fracture patterns, particularly among radiologists and surgeons who do not see a high volume of these fractures.

A final concept in the discussion of acetabular fracture imaging is delineating the weight-bearing acetabular dome. On radiographs, fractures involving a roof arc angle of less than 45° are treated as if they involve the weight-bearing dome. The roof arc angle is determined on radiographs as follows: A vertical line is drawn from the acetabular center through the acetabular dome. A second line is drawn from the acetabular center to the fracture through the acetabulum. The angle that is formed between these two lines is called the roof arc angle. The angles formed on the AP, iliac oblique, and obturator oblique radiographs are the medial, posterior, and anterior roof arc angles, respectively (Fig 17). If the roof arc angle is less than 45° on any of these three views, the fracture is considered to pass through the weight-bearing acetabular dome. If the angle is more than 45° on all views, the weight-bearing dome is spared, and the patient may be a candidate for nonsurgical management. With the advent of CT, it was determined that the cranial-most 10 mm of acetabulum, referred to as the CT subchondral arc, is equivalent to the weight-bearing dome, which is determined by using a 45° roof arc angle (Fig 17) (57,58). This equivalence can be ascertained by considering axial CT section thickness and counting images (eg, 10 images if 1-mm-thick sections are used) or by directly studying coronal and sagittal reformatted MDCT images.

How to Practically Classify an Acetabular Fracture

A question-based algorithm to systematically classify acetabular fractures into a specific Judet and Letournel fracture category was developed by Brandser et al (6,7). Despite the strength of its simplicity, this system is limited by its inclusion

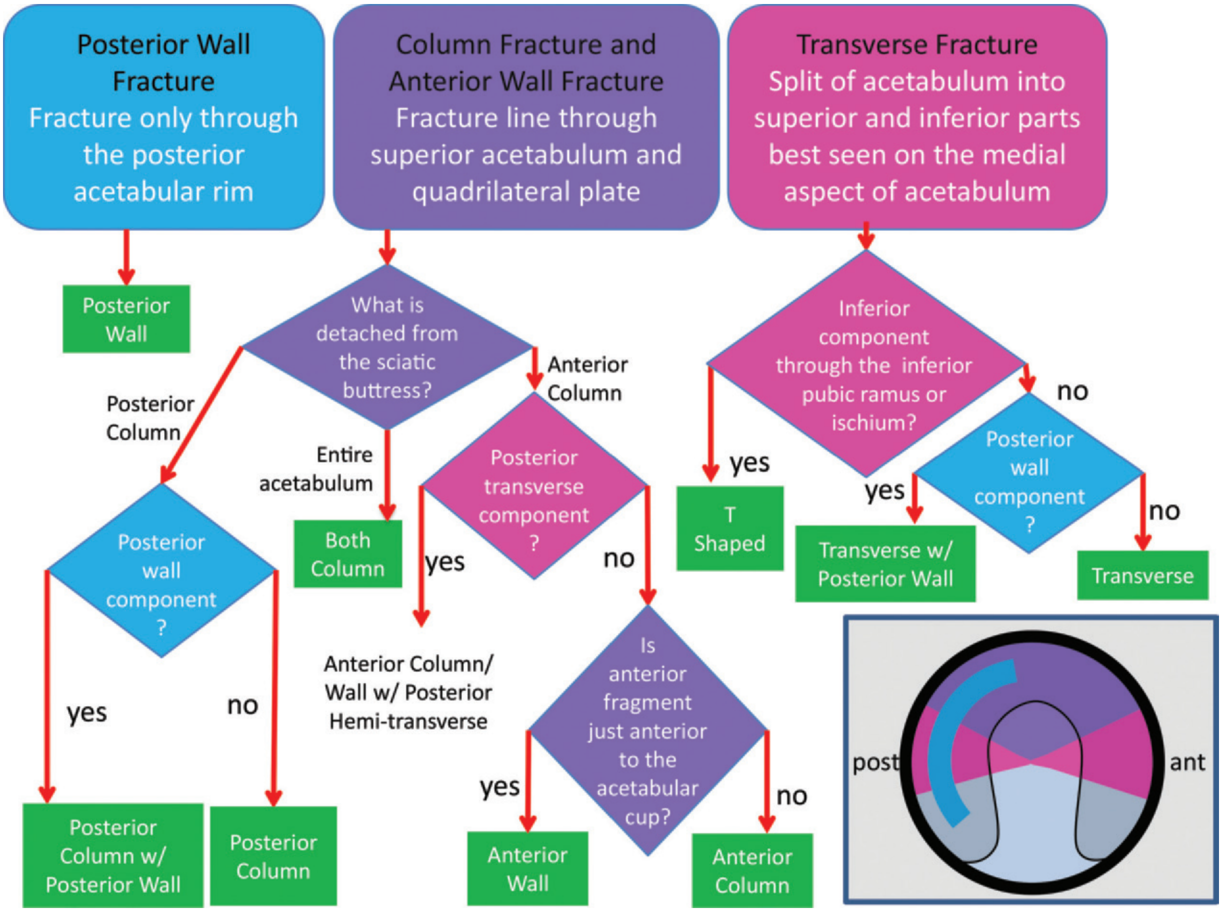


Figure 18. Flowchart shows classification of acetabular fractures with the Judet and Letournel system, with blue indicating the posterior wall, purple indicating the superior acetabulum, and pink indicating the anterior *(ant)* and posterior *(post)* portions of the acetabulum. The flowchart can be followed to arrive at the correct fracture type (green rectangle). The colors of the rectangles and diamonds correspond to those in the inset, which shows an acetabulum en face, with the articular surface shaded gray. Final diagnoses are indicated in green.

of radiographic criteria, which have been shown to be inaccurate for classifying complex fractures, even in combination with axial CT images (33). In addition, the primary branch point of the question list is whether there is interruption of the obturator ring (which would indicate a column-type or T-shaped fracture). Accurate analysis may be hampered at this branch point if the fracture line skirts the ring by extending through the ischial tuberosity (eg, a posterior column or T-shaped fracture) or if there is an "unrelated" pubic ramus fracture from disruption of the pelvic ring (3).

A general idea of what fracture type is involved may be suggested with use of axial CT images. At the level of the acetabular roof, column fractures are oriented in the coronal plane, transverse fractures are oriented in the sagittal plane, and wall fractures are oriented in the oblique plane (5,7). Still, this approach is inadequate when the associated fracture types, which have multiple fracture lines—some of which contribute to the description of the fracture category while others do not—are considered.

Our preferred method is to classify the fracture on the basis of surface-rendered 3D images. Although it may take a few extra minutes to construct the 3D model, we believe there are substantial benefits of higher confidence and greater accuracy (55,56). Once the 3D reconstruction is created, it should be oriented in the standard position, with the acetabulum en face and the acetabular notch directed inferiorly. Some may find it easiest to compare this 3D image with a standard diagram of the 10 Judet and Letournel fracture patterns (such as that shown in Fig 3 or published elsewhere) and thereby classify the fracture (2,7,13,17,38). Others may prefer an algorithmic approach. By using a flowchart like that in Figure 18, the radiologist should be directed to the correct diagnosis.

A posterior wall fracture is the only Judet and Letournel fracture that does not involve the quadrilateral plate; when there is only a fracture through the posterior acetabular rim, the diagnosis is a posterior wall fracture. When there are fracture lines that traverse the superior portion

(purple area in Fig 18) of the acetabulum (when viewed from the lateral side), classification depends on whether the anterior column, posterior column, or entire acetabulum is separated from the sciatic buttress (or sacroiliac joint). We grouped the anterior wall fracture with column fractures because, in the Judet and Letournel system, an anterior wall fracture separates a small portion of the anterior column from the sciatic buttress. When the dominant fracture lines run through the anterior and posterior acetabulum, the transverse fracture branch (pink area in Fig 18) should be followed. Analysis may be complicated by additional fracture lines that are not relevant for classification (although they may be very relevant for acetabular fixation). Therefore, when using the flowchart, the radiologist should choose the "dominant" fracture line or the most displaced component as a starting point. For example, in an anterior column with a posterior hemitransverse fracture, although there is a transverse component, because the anterior column portion is more displaced, the column pathway (purple area in Fig 18) should be used. There may be fractures that are not accounted for in the Judet and Letournel system; such fractures are also not addressed by the flowchart.

Reporting and Communicating Acetabular Fractures

It is essential to report all imaging findings that will have implications for surgical or nonsurgical repair or that will affect the patient's prognosis. With the Judet and Letournel scheme, the fracture should be categorized by analyzing the major fracture lines and subcategorized with the appropriate modifier (eg, transtectal, juxtatectal, or infratectal for transverse fractures or high, intermediate, low, or very low for anterior column fractures). Additional important bone findings include minor fracture lines; involvement of the quadrilateral plate; the presence or degree of fragment displacement, impaction, and rotation; femoral head fracture or dislocation; and the presence of intra-articular fragments (59). Involvement of the weight-bearing dome, the percentage of posterior wall involvement (for posterior wall fractures), and the presence of secondary congruence (for both-column fractures) are additional details that are fundamental for treatment decision making. Soft-tissue injuries, such as bowel, genitourinary, and vascular injuries, should be identified. Neurovascular injuries may also be suggested on the basis of the position of fracture fragments or directly depicted at MR imaging. Templating the acetabular fracture onto a pelvic model or diagram has been suggested as an essential preoperative planning step (23). Creation and storage of surface-rendered 3D images in the picture archiving and communication system (PACS) may help with this planning step.

Treatment Considerations

A detailed discussion of acetabular surgical repair is beyond the scope of this article; however, we describe key aspects of surgical decision making and technique to allow radiologists to understand the questions faced by orthopedic surgeons when considering surgical and nonsurgical management of acetabular fractures and thereby provide added value.

Once an acetabular fracture is diagnosed, there are a few treatment options, including traction (formerly the primary treatment strategy), early mobilization with variable weight bearing (eg, a stable fracture with minimal displacement), open reduction and internal fixation, and primary hip arthroplasty (60). Long-term outcome correlates with the type of fracture, the amount of acetabular comminution and impaction, involvement of the weight-bearing dome, the presence of concomitant pelvic ring fractures, and the quality of surgical reduction (19,23,36).

Polytrauma patients may present with hemodynamic instability, which must be addressed with advanced trauma life support protocols. Life-threatening hemorrhage is usually not the result of an acetabular fracture (61). Once the patient is hemodynamically stabilized, it is determined whether surgical management is indicated.

General criteria for surgical management include displacement of more than 2 mm within the weight-bearing acetabular dome, instability of the femoral head, intra-articular fragments, soft-tissue interposition between fracture fragments, and lack of secondary congruence of an associated both-column fracture. Specifically for posterior wall fractures, indications for surgery include instability of the femoral head from the acetabulum, marginal impaction of the articular surface, and intra-articular fragments (41). By using preserved cadaveric specimens, it was found that posterior wall fractures that involve less than 25% of the width of the posterior wall are stable, those that involve more than 50% of the width of the posterior wall are unstable, and the stability of those that involve 25%–50% of the width of the posterior wall is dependent on the integrity of the joint capsule (62). By using transverse measurements on CT images of fresh cadaveric specimens, it was determined that posterior wall fractures that involve less than 20% of the width of the posterior wall are

stable, and those that involve more than 40% of the width of the posterior wall are unstable (63). For fractures in the intermediate range, an examination to test for joint stability may be performed in the operating room with the patient under anesthesia (61,64).

There are also imaging criteria that support nonsurgical management. For fractures other than posterior wall or associated both-column fractures (which have different criteria), if the roof arc angle is more than 45° on all radiographic views or the fracture does not cross the 10-mm CT subchondral arc, the weight-bearing dome is not involved and surgery is not indicated. Even within the weight-bearing dome, fractures with less than 2 mm of displacement may not require surgery (17,65,66). Regarding posterior wall fractures, as was previously noted, a fracture that is less than 20% of the width of the posterior wall may be treated nonsurgically, whereas larger fractures may require surgical intervention. Secondary congruence may be a goal in certain patients with an associated both-column fracture and may indicate nonsurgical management; however, it may result in limb shortening and medialization of the femoral head, which may not be well tolerated biomechanically (23).

Aside from the actual fracture configuration, other considerations that favor nonsurgical treatment are local or systemic infection and severe osteoporosis. Among elderly patients in particular, if the fracture is displaced less than 2 mm, pain management, physical therapy, early mobilization, and obtaining weekly radiographs may be considered in the presence of severe osteopenia, which does not provide adequate support for internal fixation, or if there is concurrent illness (24,25).

Operative Acetabular Repair

The goals of surgery are to restore the articular surface, restore congruence of the femoral head with the acetabulum, allow early mobilization, and provide pain-free hip function (15). Acetabular surgery is complicated because of the 3D anatomy of the pelvis and acetabulum, the complex fracture patterns that may be encountered, and the potential for concomitant traumatic injuries (67). Some authors believe that surgical fracture treatment should be performed only at specialized centers; however, even complex repairs are increasingly being attempted outside such centers (42,68). Surgical repair is most commonly performed by orthopedic surgeons with open techniques. In select situations, repair can be performed by surgeons or radiologists with percutaneous screw placement or with hybrid percutaneous or minimally invasive approaches (69–73).

The technical goal of surgery is to reduce all fracture fragments with residual displacement of less than 2 mm to optimize biomechanics and allow maximal contact between the acetabular articular surface and the femoral head. If there is residual displacement, supraphysiologic stress is placed on the contact area, which leads to articular cartilage breakdown and early arthritis (17). In a meta-analysis of 2424 fractures, satisfactory reduction with less than 2-mm displacement was possible in 86% of cases (19).

The timing of surgery is also an important consideration. Indications for immediate surgery include hip dislocation that cannot be reduced because of the increased risk for femoral head osteonecrosis, reduction that cannot be maintained nonsurgically, increased neurologic deficit after reduction, evidence of pressure on a nerve, open fracture, and vascular injury (60). Otherwise, surgery is usually performed 2–3 days after the injury to allow other injuries to stabilize. The preferred time frame for operative management is within 10 days, after which callus formation makes reduction and internal fixation more difficult (17).

Part of the innovation of Judet and Letournel was in their description of surgical approaches to the hip for reducing and fixing acetabular fractures. These descriptions are still used, with the most common approaches being the posterior Kocher-Langenbeck exposure, in which patients are positioned prone or in the lateral decubitus position; the anterior ilioinguinal exposure, in which patients are positioned supine; and the lateral extended iliofemoral exposure, in which patients are positioned in the lateral decubitus position (4,41). A single approach with minimal soft-tissue damage is preferred for acetabular fixation but is not always achievable (19). The Kocher-Langenbeck approach is used to repair posterior wall, posterior column, posterior column with posterior wall, transverse, and transverse with posterior wall fractures (except for transtectal fractures, which may require an extended iliofemoral approach). The ilioinguinal approach is used for anterior wall, anterior column, and anterior wall or column with posterior hemitransverse fractures (although a combined Kocher-Langenbeck and ilioinguinal exposure may be necessary) and is most associated with both-column fractures (although they may require a combined Kocher-Langenbeck and ilioinguinal approach or an extended iliofemoral approach). The extended iliofemoral approach yields the greatest exposure but causes the most soft-tissue trauma. It is used for T-shaped fractures (which may also require a combined Kocher-Langenbeck and ilioinguinal exposure) and as many as one-third of associated both-column fractures.

Each fracture type has specific issues that must be addressed. For example, posterior wall fractures commonly have impacted articular fragments that are repaired with elevation and buttressing to restore the articular surface (4,17). T-shaped fractures are difficult to repair because of separate free inferior-anterior and inferior-posterior fragments; reduction of just the anterior or just the posterior fragment will not restore the acetabulum (36).

Although the goal is usually to restore the acetabular articular surface, total hip replacement may be performed, particularly in elderly patients for whom adequate fixation is thought to be difficult or impossible because of suboptimal bone stock. Although uncommon, this approach may be used in patients with anterior column or anterior column or wall with posterior hemitransverse fractures, both of which are common in elderly patients (17). Failure to achieve an adequate initial reduction may result in delayed hip arthroplasty for posttraumatic degenerative joint disease.

Complications Associated with Acetabular Fractures

Acetabular fractures are associated with several iatrogenic injuries, as well as short- and long-term complications. Traumatic nerve palsies may occur as a result of the initial injury. Injury to the sciatic nerve, which runs just posterior to the acetabulum, occurs in 16% of all acetabular fractures but has a higher incidence in patients with posterior hip dislocation (19). Iatrogenic sciatic, femoral, or lateral femoral cutaneous nerve palsy occurs in as many as 15% of patients who undergo acetabular fracture fixation (19,23,74). These nerve palsies usually resolve with time, but it can take years (4,74,75). Mechanical sequential compression or subcutaneous heparin is used as prophylaxis for deep venous thrombosis (19,23). Nevertheless, deep venous thrombosis is diagnosed in as many as one-third of patients with acetabular fracture, and inferior vena caval filters or pharmacologic anticoagulation therapy is used to prevent pulmonary embolism (41,76).

Infection after surgical acetabular fixation may necessitate hardware removal and destroy articular cartilage, leading to a poor outcome (23,41). Preoperative pelvic arterial embolization, a coexisting Morel-Lavallée lesion, elevated body mass index, and a stay in the intensive care unit have been identified as risk factors for deep wound infection after acetabular fixation (77,78).

Each surgical approach has known complications. Iatrogenic sciatic nerve injury is most common with the Kocher-Langenbeck approach; electromyography monitoring may help prevent this complication (41,79). Heterotopic ossification is most common with the extended iliofemoral approach and least common with the ilioinguinal approach (41).

Long-term complications include early osteoarthritis, heterotopic bone formation, femoral head osteonecrosis, nonunion, and malunion. Osteoarthritis occurs in approximately 20% of patients with repaired acetabular fractures; however, some diagnoses may be radiographic but asymptomatic (4,19). Fractures not involving the acetabular weight-bearing dome have a lower incidence of osteoarthritis (80). Although osteoarthritis may occur in perfectly repaired fractures, it is much more common in poorly reduced fractures. Recent evidence demonstrates that fractures that appear to be perfectly reduced at radiography have substantial displacement (ie, more than 2 mm) at CT (81). This may explain the development of osteoarthritis in patients with presumed perfect reductions. Heterotopic bone formation, which may or may not limit range of motion, occurs postoperatively in 6% of patients (19). Indomethacin has not been shown to decrease heterotopic bone formation, but radiation therapy has proven to be effective for this function (82–84). Osteonecrosis of the femoral head may occur after acetabular fracture, with a higher incidence when associated with a posterior hip dislocation (19). Nonunion or malunion occurs in 8% of patients and requires total hip arthroplasty, revision fixation, or arthrodesis (19).

Conclusions

Classification of acetabular fractures with the Judet and Letournel system is not intuitive but can be performed efficiently with careful and systematic analysis. The goals of imaging are to identify factors that are therapeutically relevant, including accurate fracture classification. Identification of associated bone injuries that must be addressed at the time of surgery is critical, and identification of associated soft-tissue injuries may help avoid intra- or postoperative complications. The primary goal of surgery is to restore the acetabular articular surface and facilitate restoration of function. Careful image reconstruction, analysis, and communication by the radiologist working closely with a skilled orthopedic surgeon allows for the best possible outcome for these complex fractures.

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