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Conventional Radiographs to Assess Femoroacetabular Impingement

Moritz Tannast, MD
Klaus A. Siebenrock, MD

Abstract

Femoroacetabular impingement (FAI) is a pathologic condition of the hip joint in young adults that, if untreated, leads to end-stage osteoarthritis. It is characterized by early pathologic contact between primary osseous prominences of the acetabular rim (so-called pincer FAI) and/or the femoral head-neck junction (cam FAI). Conventional radiographs are often considered normal because classic radiographic signs of osteoarthritis are not present initially. The physician should be aware of the radiographic features for both types of impingement to recognize subtle pathologies.

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Femoroacetabular impingement (FAI) is a purely mechanical hip disorder defined as abnormal contact between skeletal prominences of the acetabular rim or the proximal femur that leads to painful, prearthritic joint damage.[1] The estimated prevalence is 10% to 15%.[2] If untreated, FAI can lead to end-stage osteoarthrosis of the hip joint and may be one of the main causes of so-called primary osteoarthritis of the hip. Generally, FAI occurs as an isolated entity but can also present in combination with various hip disorders, such as developmental dysplasia or Legg-Calvé-Perthes disease (Table 1). The diagnosis of FAI is based on a positive correlation among symptoms, physical findings on clinical examination, suggestive conventional radiographs, and signs of chondrolabral degeneration on radial magnetic resonance arthrography. In the early stage of the disease, no classic signs of osteoarthritis (such as joint space narrowing, subchondral sclerosis, or bone cysts) are obvious on conventional radiography, although cartilage degeneration is already advanced.

Clinical Signs of Impingement

FAI often presents in active, young adults as groin pain of slow onset, usually noticed after an episode of minor trauma. The pain is intermittent and may be exacerbated by excessive physical demands on the hip, such as athletic activities or a normal activity of daily living such as walking. The pain also may occur after a prolonged period of sitting. Based on normal-appearing radiographs of the hip, patients with FAI sometimes are subjected to an extensive diagnostic work-up and even inappropriate surgical procedures.[1] Examination of the hip often reveals limited motion, particularly internal rotation and adduction in flexion.[3] A positive impingement sign is seen for anterior FAI if the forced internal rotation or adduction in 90° of flexion is reproducibly painful and for posterior FAI if forced external rotation in full extension is painful. The Drehmann sign is positive if hip flexion produces unavoidable passive external rotation of the hip. A positive impingement test has been closely correlated with labral lesions, as seen on specific radial magnetic resonance arthrograms of the hip.[4]

Radiographic Technique

Standard conventional radiographs for FAI include an AP pelvis radiograph and an axial cross-table view of the proximal femur.[5,6] The AP pelvis radiograph is taken with the patient supine and the legs internally rotated (to adjust for femoral antetorsion), with a film focus distance of 1.2 m. Obtaining a radiograph with the patient supine allows direct comparison with intraoperative and immediate postoperative radiographs during general anesthesia. The central beam should be directed to the midpoint between the superior border of the symphysis and a line connecting both the anterior and superior iliac spines, landmarks that can be easily and reproducibly palpated by the radiology technician. Centering of the beam is crucial and

Table 1
Description and Characteristics of the Two Types of Femoroacetabular Impingement

Criteria	Pincer Impingement	Cam Impingement
Main cause	Focal or general overcoverage	Aspherical head
Mechanism	Linear contact between overcovering rim and head-neck junction	Jamming of the aspherical head portion into the acetabulum
Gender distribution (M:F)	1:3	14:1
Average age (range)	40 years (40-57)	32 years (21-51)
Typical location of cartilage damage	Circumferential with contre-coup lesion	11 o'clock-3 o'clock
Average depth of cartilage damage	4 mm	11 mm
Associated pathologies	• Bladder extrophy • Proximal femoral focal deficiency • Posttraumatic dysplasia • Chronic residual dysplasia of the acetabulum • Legg-Calvé-Perthes disease • Slipped capital femoral epiphysis • After acetabular reorientation procedures • Idiopathic retroversion	• Slipped capital femoral epiphysis • Legg-Calvé-Perthes disease • Posttraumatic retrotorsion of the femoral head • Coxa vara • Pistol grip deformity • Head tilt deformity • Postslip deformity • Femoral retroversion • Growth abnormality of the femoral epiphysis
Radiographic signs on AP radiograph	• Coxa profunda • Protrusio acetabuli • Focal acetabular retroversion (figure-of-8 sign) • Lateral center edge (LCE) angle > 39° • Reduced extrusion index • Acetabular index ≤ 0° • Posterior wall sign • Ischial spine sign	• Pistol grip deformity • Triangular index R ≥ r + 2 mm* • Alpha angle > 68° (men) • Alpha angle > 50° (women) • Caput-collum-diaphyseal (CCD) angle < 125° • Horizontal growth plate sign
Radiographic signs on cross-table radiograph	• Linear indentation sign	• Alpha angle > 50° • Femoral offset < 8 mm • Offset ratio < 0.18 • Femoral retrotorsion
Secondary changes	• Herniation pits • Ossification of labrum • Appositional bone sign • Os acetabuli (acetabular rim fracture) • Posterior inferior joint space loss (on false profile view in pincer hips) • Late: classic signs of osteoarthritis	

*See text for explanation.

is different from preoperative planning for a total hip arthroplasty, where it is directed more caudally. The axial cross-table femoral view is also taken with the leg internally rotated, with a film-focus distance of 1.2 m and with the central beam directed toward the inguinal fold.[5] These technical prerequisites are mandatory for correct interpretation.

A false profile view[7] is rarely used for diagnosis because it does not show the relationship between the anterior and posterior acetabular walls. Rather, it can be used for the diagnosis of early joint degeneration in the posteroinferior part of the acetabulum, which is a relative contraindication for joint-preserving surgery described later in this chapter. As an alternative to the cross-table lateral view, a Dunn-Rippstein view[8] or a frog-leg lateral view[9] can be obtained for visualizing a cam deformity. To accurately measure a patient's pelvic tilt, a true lateral radiograph of the pelvis can be taken.[5] Knowledge of pelvic tilt is crucial for correct interpretation of the radiographic hip parameters. Gonadal shielding is not recommended because it can potentially hide important anatomic landmarks needed to quantify pelvic tilt and rotation.

Types of Impingement

Depending on the pathomechanism, two types of FAI, pincer and cam, can be distinguished (Figures 1 and 2). Isolated cam or pincer deformities are rare; in 86% of all affected patients a combined deformity is present.[10]

Pincer Impingement

In pincer impingement, a linear contact occurs between the acetabular rim and the femoral head-neck junction, with the maximal impact force tangential to the joint surface (Figure 2). The labrum (which acts like a bumper) is compressed between the two impinging bones and tears off its acetabular origin. The force is then further transmitted to the acetabular cartilage. In this type of impingement, the transmission of force to the cartilage is restricted to a narrow band of the acetabular rim. Therefore, these lesions are typically more benign in terms of visible cartilage damage than those seen in cam impingement. Generally, pincer impingement is caused by a focal or general acetabular overcoverage with a relatively normal femur, or rarely a large deformation of the femoral head. Repeated microtrauma induces cystic deformations of the labrum and bone growth at its base that subsequently ossifies. This rim ossification is responsible for additional deepening of the acetabulum and worsening impingement. Pincer impingement is more common in middle-aged women. The condition can occur as an isolated entity, in combination with various hip disorders, or iatrogenically (for example, after overcorrection in acetabular reorientation procedures [Table 1]).

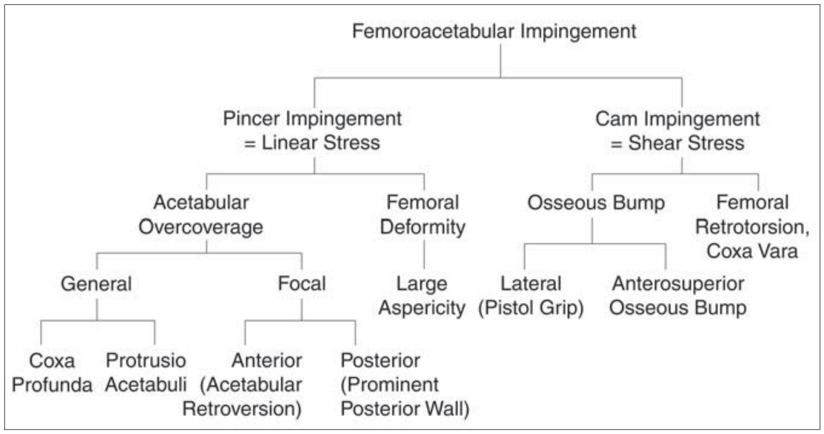

Figure 1 Overview of the different types of impingement.

General Acetabular Overcoverage

General acetabular overcoverage can be judged by the depth of the acetabular fossa. With normal depth, the acetabular fossa is lateral to the ilioischial line (Figure 3, *A*); with coxa profunda the acetabular fossa is touching or crossing the ilioischial line (Figure 3, *B*). With protrusio acetabuli, which represents the worst type of general overcoverage, the femoral head is crossing the ilioischial line (Figure 3, *C*). These joint configurations are primary pathologies and cannot be compared with secondary acetabular protrusion in end-stage osteoarthritis.

Coxometric measurements to quantify acetabular depth include the lateral center edge (LCE) angle of Wiberg, the acetabular index, and the femoral head extrusion index (Figure 3). The LCE angle is defined by a vertical line starting from the center of the femoral head and parallel to the longitudinal body axis and a line connecting the femoral head center with the lateral edge of the acetabular roof. Normally, this angle varies between 25° (defining a deficient acetabular coverage) and 39° (defining excessive coverage, Figure 3, *A*). The acetabular index (also called acetabular roof angle) is formed by a horizontal line and a line through the medial edge of the sclerotic zone and the lateral edge of the acetabulum. In hips with coxa profunda or protrusio acetabuli, the acetabular index typically is 0° or even negative (Figure 3, *B* and *C*). The femoral head extrusion index is defined as the horizontal portion of the femoral head that is uncovered by the acetabulum. Although there is a maximal extrusion of 25% (indicating dysplasia), no study has defined a minimal extrusion index.

It is assumed that the abrupt stop in pincer FAI leads to a slight joint subluxation with resulting joint damage in the opposite part of the joint (Figure 2). It can be seen in approximately one third of all patients with pincer impingement.[10] This posteroinferior joint damage can be seen as a subtle joint space narrowing on the false profile view, indicating an already advanced stage of joint degeneration with a limited prognosis (Figure 4). Therefore, this condition is a relative contraindication for joint-preserving surgery.

Hip radiographs made with the beam centered over the hip can show false depth of the acetabulum and are therefore not useful for interpreting radiographic signs of FAI (Figure 5). In addition, hip radiographs do not show the entire pelvis. This finding is important because anatomical reference lines (for example, the interteardrop line) cannot be determined.

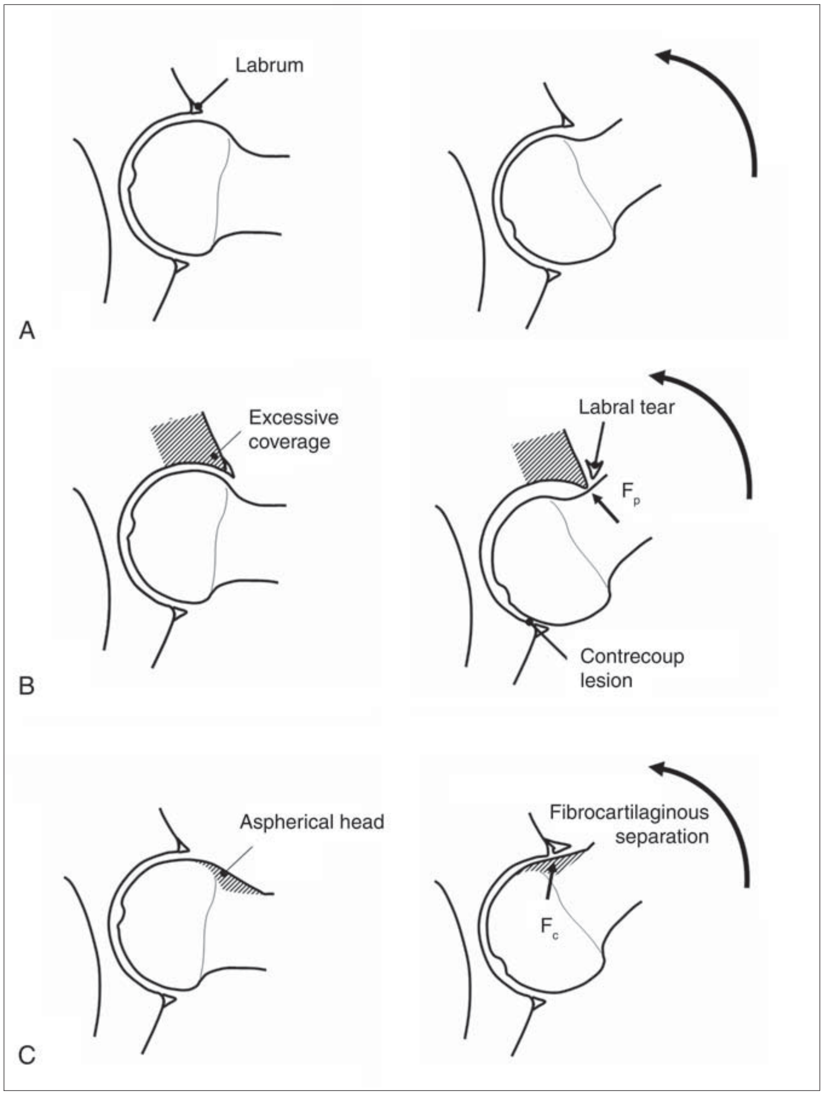

Figure 2 A normal hip **(A)** has an impingement-free range of motion within the physiologic amplitudes of joint motion. In pincer impingement **(B)**, the main impact force F_P is directed tangential to the joint surface, leading to a full tear of the labrum (mainly resulting from to acetabular overcoverage). In cam impingement **(C)**, the aspherical portion of the femoral head-neck junction is jammed into the acetabulum. The main impact force F_C is perpendicular to the joint surface, leading to a fibrocartilaginous separation (undersurface tear of the labrum).

Focal Acetabular Overcoverage

Focal acetabular overcoverage can occur in the anterior or posterior portion of the acetabulum. It can be assessed by carefully tracing the anterior and posterior acetabular walls on an AP radiograph. In a normal hip, the acetabulum is anteverted; the anterior wall runs medial to the posterior rim without crossing it (Figure 3, *A*). In relative anterior overcoverage, the anterior rim is projected more lateral than the posterior rim in the cranial part of the acetabulum. It crosses the posterior line caudally, which gives the appearance of a figure-of-8 sign (Figure 6). Often with this so-called acetabular retroversion, the ischial spine crosses the true pelvis medially (Figure 6, *A*).

Posterior acetabular coverage can be evaluated by determining the position of the posterior acetabular rim relative to the femoral head center. In a normal hip, the posterior border runs approximately through the femoral head center (Figure 3, *A*). With a too-prominent posterior wall, the projected line runs lateral to the femoral head center, indicating posterior FAI in extension and external rotation (Figure 6, *B*).

Differentiation of the anterior and posterior acetabular walls is sometimes difficult. As a helpful hint in clinical practice, the posterior wall can easily be identified when starting from the inferior edge of the acetabulum.

A positive crossover sign has to be assessed with caution if the technical radiographic prerequisites are not fulfilled. A crossover sign can be missed if the center of the beam is directed over the hip (Figure 7). Because of the conical geometry of the beams, the crossover sign can be increased if the film-focus distance is decreased (Figure 8).

In addition, acetabular retroversion can be created by an increased pelvic tilt or rotation to the ipsilateral side of the patient (Figure 9). Neutral pelvic rotation around the longitudinal axis is obtained when the tip of the coccyx points toward the middle of the symphysis. In men and women, neutral pelvic tilt around the horizontal axis can be roughly defined by a distance of 3.2 cm or 4.7 cm, respectively, between the upper border of the symphysis and the middle of the sacrococcygeal joint. To accurately determine individual pelvic

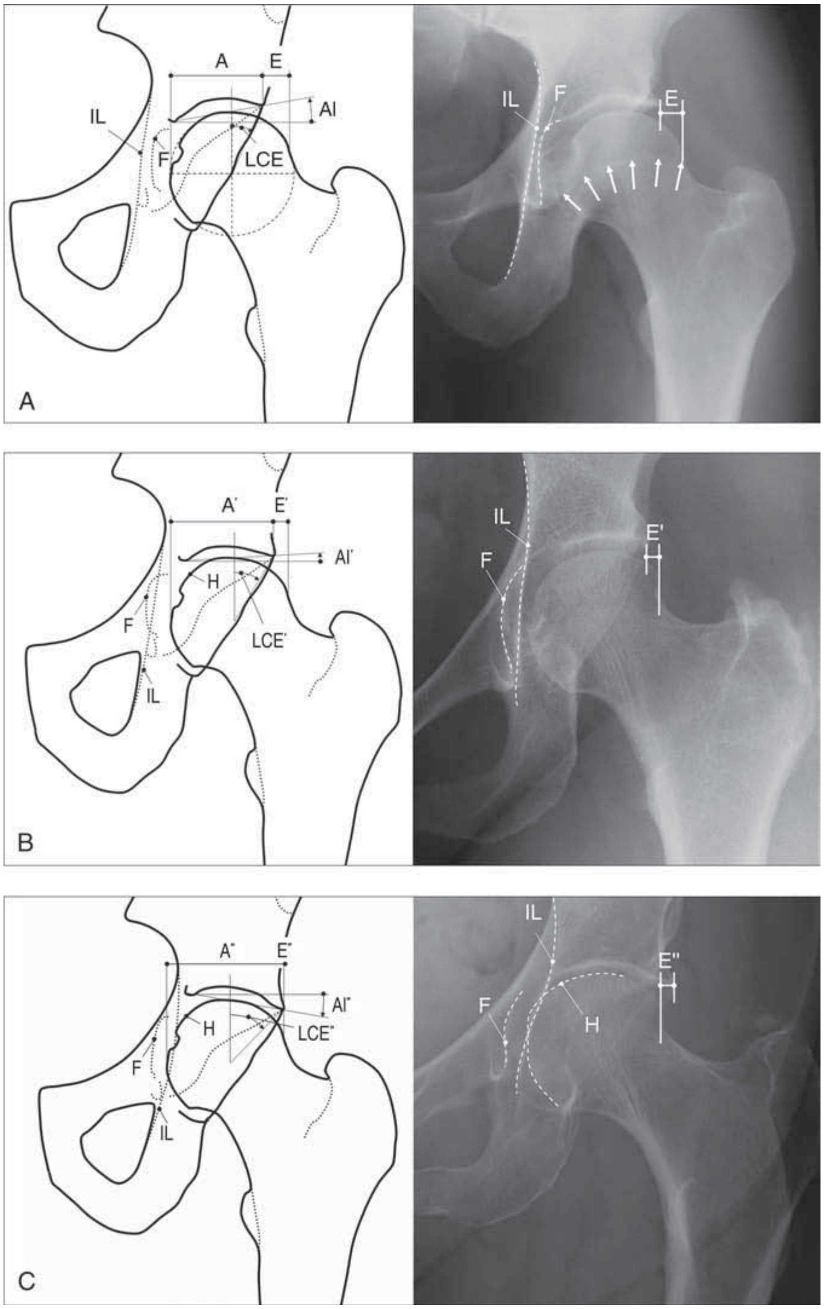

Figure 3 **A,** A normal hip with normal depth in a 35-year-old man. The acetabular fossa (F) lies lateral to the ilioischial line (IL). The lateral center edge (LCE) angle is between 25° and 39°. The extrusion index (E/[A + E]) is approximately 25%. The epiphyseal scar (arrows) lies within the femoral head circle. The acetabular index (AI) is slightly positive. The posterior wall goes through the femoral head center. See text for additional discussion. **B,** Coxa profunda in a 29-year-old woman is shown. The condition is defined by an overcrossing of the acetabular fossa with the IL. The AI and the femoral head extrusion are decreasing, the LCE angle is increasing. **C,** In protrusio acetabuli in a 42-year-old woman, even the femoral head line is crossing the IL.

Figure 4 Because of the contrecoup lesion in the hip of a 36-year-old woman with pincer impingement, joint-space narrowing of the posteroinferior articular portion is visible on a false profile view (*arrow*).

tilt, a true lateral pelvic radiograph can be obtained.[3] A neutral pelvic tilt is indicated by 60° of pelvic inclination, which is defined by a horizontal line and a line connecting the symphysis with the sacral promontory. Modern software is available to correct the individual acetabular morphology to a standardized neutral orientation;[11] however, it still has to be shown if such an anatomically based standardization corresponds to the clinical symptoms.

Pincer impingement can lead to an indentation sign on the femoral side with compensatory cortical thickening (Figure 10). Pincer impingement also can occur without specific pathomorphology in patients with excessive hip motion, typically young hypermobile women (for example, ballet dancers).

Large Deformation of the Femoral Head

In rare instances, pincer impingement is caused by a large, deformed femoral head, typically in hips with

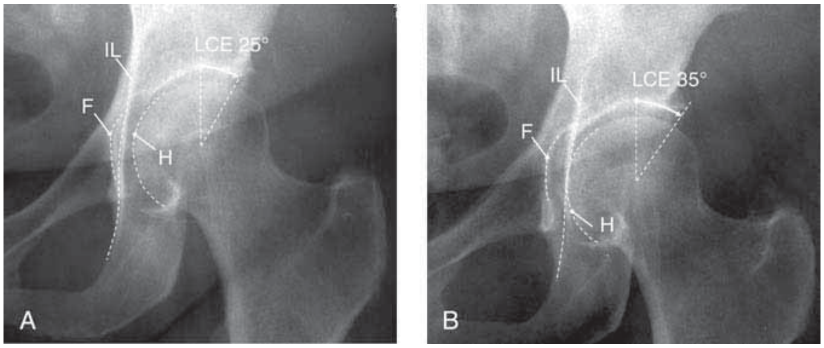

Figure 5 **A,** Radiograph of the hip of a 35-year-old woman shows a coxa profunda with an LCE angle of 25° if the beam is correctly centered over the pelvis. **B,** If the beam is directed over the hip, protrusio acetabuli is visible with a substantially increased LCE angle of 35°.

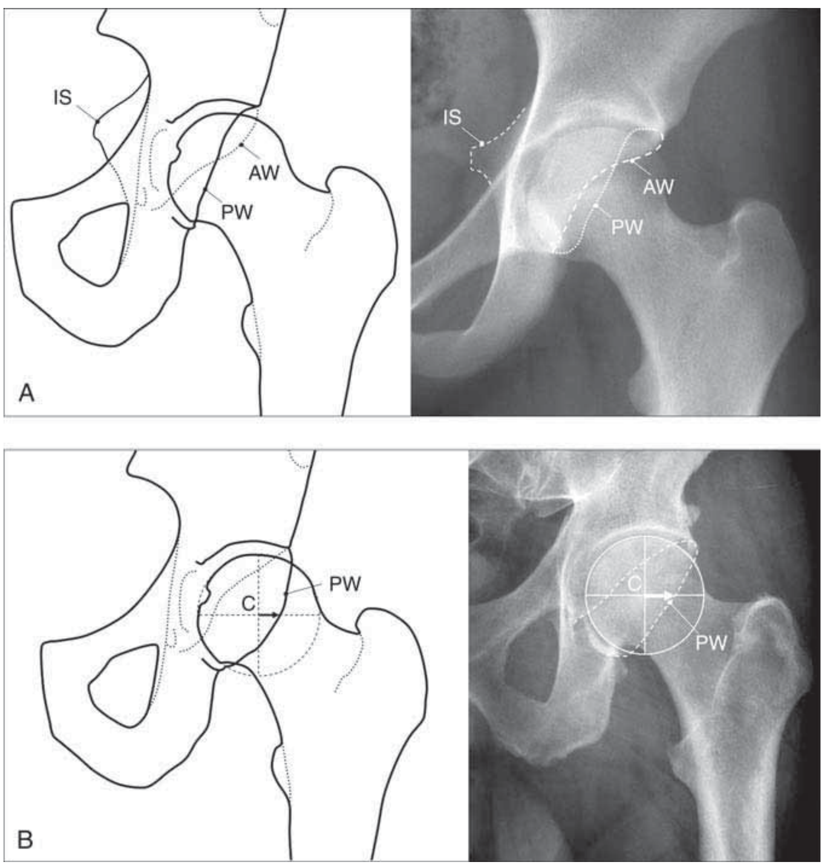

Figure 6 **A**, Drawing and radiograph of the hip of a 24-year-old patient show an acetabular retroversion with relative anterior overcoverage where the anterior wall (AW) crosses the posterior wall (PW), causing a figure-of-8 sign. As an indirect indicator, the ischial spine (IS) protrudes into the true pelvis. **B,** Drawing and radiograph of the hip of a 32-year-old man show posterior overcoverage, which is defined with the PW running lateral to the femoral head center (C). In normal hips, it runs approximately through the center (see Figure 3, *A*).

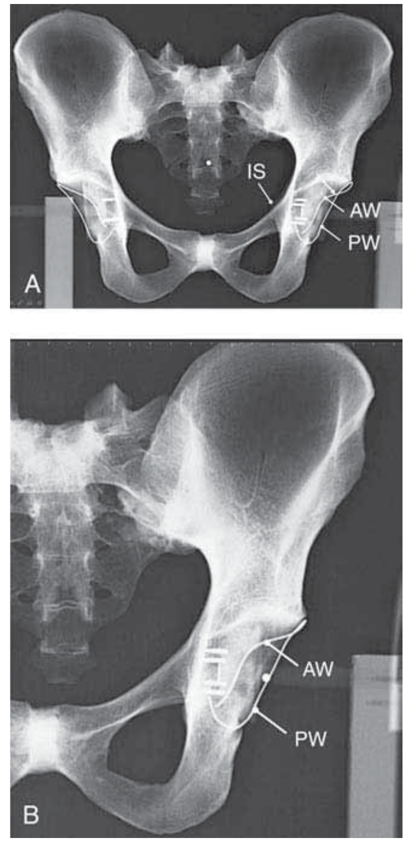

Figure 7 **A,** The correctly centered AP pelvic radiograph shows a cranial retroversion of the left acetabulum in a female cadaver pelvis. The center of the x-ray beam is marked with a radiodense ball. The ischial spine (IS) sign is positive. **B,** If the x-ray beam is centered over the hip, the crossover and the IS sign disappear.

Legg-Calvé-Perthes disease. Because the femoral head is too large to enter the joint, this leads to an abrupt stop at the final range of motion. These hips often show a femoral indentation corresponding to the early pathologic contact of the acetabular rim (Figure 11).

Secondary Changes in Pincer Impingement

Recurrent irritation in unrecognized pincer FAI leads to reactive ossification of the labrum (Figure 12). This also can be seen as a double contour of one of the projected acetabular rims. In an advanced stage, further deepening of the acetabulum is caused by additional reactive bone apposition at the osseous acetabular rim, thereby increasing impingement. Although there is significant and irreversible prearthritic damage of the cartilage, there is no joint space narrowing because only the quality of the cartilage and not its diameter is impaired in the early stage of the disease. Classic radiographic signs of osteoarthritis occur late and indicate advanced joint degeneration, a relative contraindication for joint-preserving surgery.

Cam Impingement

In cam impingement, the predominant abnormality is the contour of the anterosuperior femoral head-neck junction (Figure 2). The shearing stress between the femoral head-neck junction and the acetabulum is caused either by an irregularity of the femoral head-neck junction or by angular deformities of the proximal femur[12] (Figure 2; Table 1). Normally, the anterosuperior femoral head-neck junction has a concave, spherical configuration that is either flattened or convex in hips with cam impingement. This eccentric part slides into the acetabulum and induces compression and shear stress at the junction between the labrum and the cartilage and at the subchondral landmark. In contrast to pincer impingement, the maximal impact force is perpendicular to the joint surface (Figure 2). Therefore, the labrum is stretched and pushed outward, and the cartilage is compressed and pushed centrally, causing a separation between the labrum and the cartilage. The labrum with this undersurface lesion of its matrix remains partially attached on the acetabular rim.

The osseous irregularity can occur in the lateral (so-called pistol-grip deformity) or in the anterosuperior part of the femoral head-neck junction. Angular deformities include femoral retrotorsion and coxa vara. Cam impingement is most common in young athletic males.

Pistol-Grip Deformity

A pistol-grip deformity occurs in approximately 6% of men and 2% of women.[13] It is characterized on AP radiographs by flattening of the usually concave surface of the lateral aspect of the femoral head caused by an abnormal extension of the more horizontally oriented femoral epiphysis. It can be quantified by the α angle and the triangular index.[13]

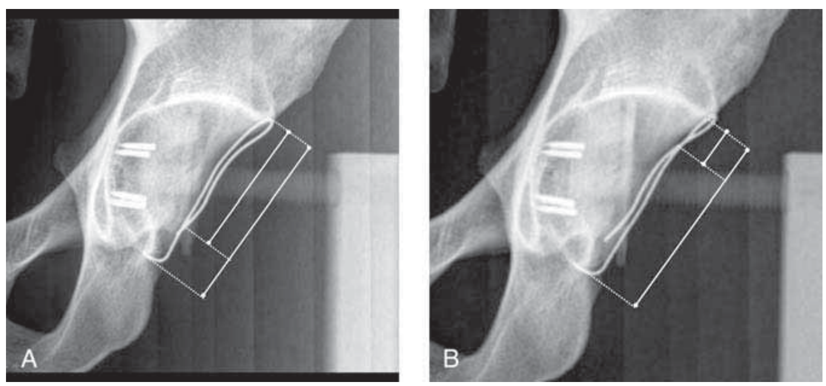

Figure 8 By changing the source-to-film distance, different projections of the acetabular morphology for this cadaver pelvis can be obtained. **A,** Radiograph showing a source-to-film distance of 0.8 m with large acetabular retroversion. **B,** Radiograph showing a source-to-film distance of 1.4 m; the retroversion index is reduced.

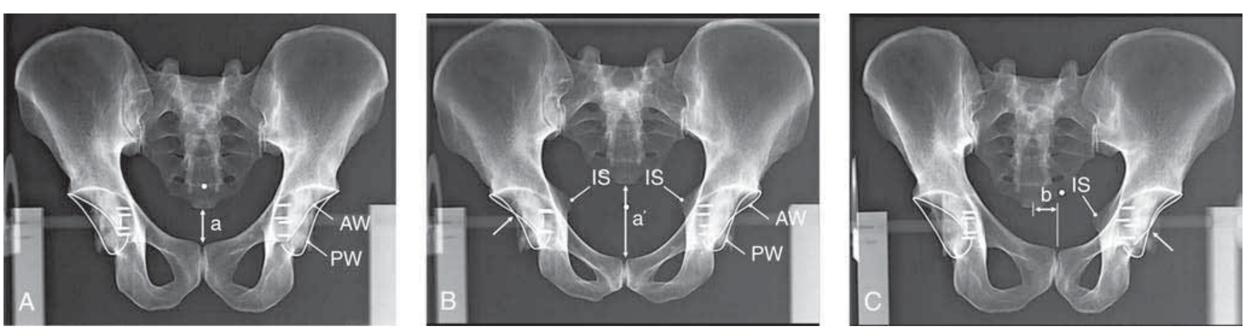

Figure 9 **A,** Radiograph showing normal acetabular version on both sides of a cadaver pelvis. **B,** By increasing pelvic tilt, an acetabular retroversion is visible on both sides. In addition, the ischial spine (IS) sign is positive. **C,** By rotating the pelvis to the left side, a crossover and IS sign can be created at the ipsilateral side.

The α angle is formed by the femoral neck axis and a line connecting the femoral head center with the point of beginning asphericity of the superior femoral head contour (Figure 13). This point can be determined with the Mose template method of concentric circles. The α angle can be underestimated if the femoral rotation is not controlled. The maximal normal α angle on the AP pelvic radiograph is 68° in men and 50° in women.[13]

The triangular index (Figure 13) is constructed as follows: on the femoral neck axis, half of the radius of the femoral head is measured. Then, a perpendicular line is drawn. The new radius is defined as the distance between the femoral head center and the intersection point of the perpendicular line with the superior femoral head-neck contour. The triangular index has better reproducibility than the α angle because it is constructed by clear geometric landmarks, whereas the α angle sometimes can be difficult to pinpoint. In addition, the triangular index is more independent from femoral rotation.[13]

Anterosuperior Osseous Bump

The anterosuperior osseous bump at the femoral head-neck junction cannot be seen on the AP pelvis radiograph, but it can be seen on additional radiographic views of the proximal femur such as the cross-table lateral view. It can be a primary osseous variant of the femoral head-neck junction or the result of subclinical slipped capital femoral epiphysis or Legg-Calvé-Perthes disease (Table 1). In addition, the anterosuperior osseous bump is seen in malunited femoral neck fractures.

As on the AP view, the amount of asphericity can be quantified on the lateral view by the α angle (Figure 14). The anterior femoral offset and the offset ratio also are used for description. An α angle larger than 50° is an indicator of an abnormally shaped femoral head-neck contour. The anterior offset is defined as the difference in radius between the anterior femoral head and the anterior femoral neck. In asymptomatic hips, the anterior offset is 11.6 ± 0.7 mm; hips with cam impingement have a decreased anterior offset of 7.2 ± 0.7 mm.[6] As a general rule for clinical practice, an anterior offset less than 10 mm is a strong indicator of cam impingement. The offset ratio is defined as the ratio between the anterior offset and the diameter of the head. It is 0.21 ± 0.03 in asymptomatic patients and 0.13 ± 0.05 in hips with cam impingement.[6]

It is important to recognize that these deformities are primary deformities, not osteophytes.

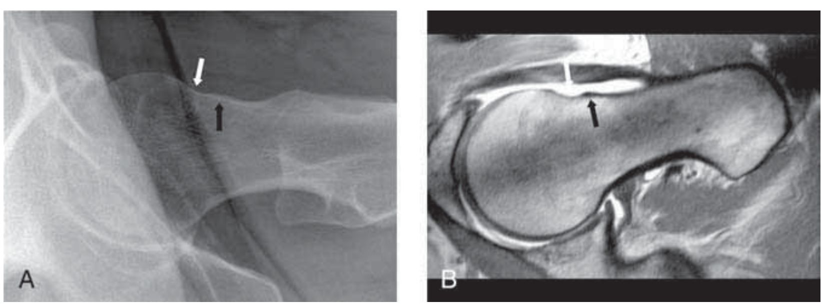

Figure 10 Cross-table lateral view **(A)** and corresponding magnetic resonance arthrogram **(B)** showing an indentation sign (*arrows*) on the femoral head-neck junction in a 38-year-old woman with pincer impingement.

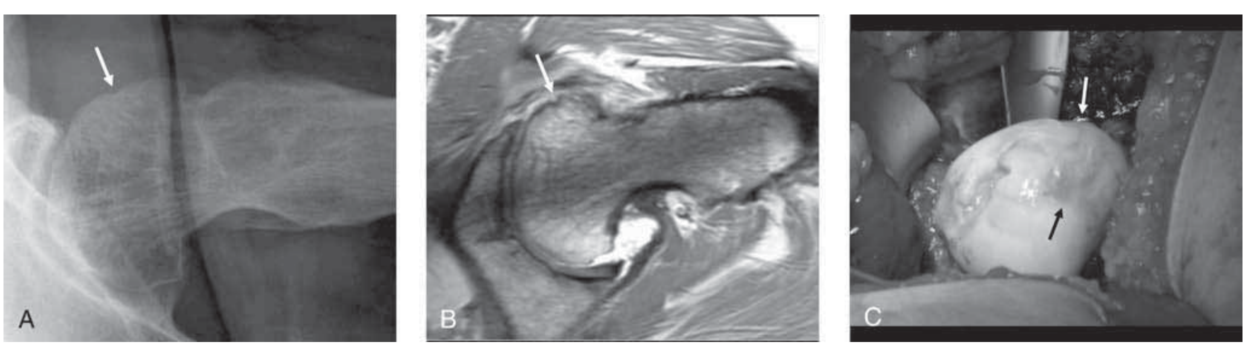

Figure 11 Pincer impingement caused by an extremely large femoral head that cannot enter the joint in a 28-year-old patient with Legg-Calvé-Perthes disease. Note the indentation (*arrows*) on the cross-table lateral view **(A)** the corresponding magnetic resonance arthrogram **(B)** and on an intraoperative view **(C)**.

Figure 12 Radiograph showing secondary signs of FAI in the hip of a 34-year-old woman with coxa profunda: labral ossification (*arrow*).

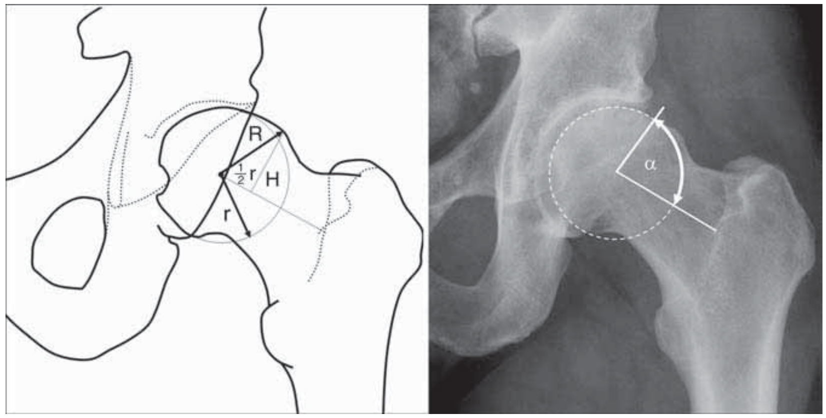

Figure 13 Drawing and radiograph from a 25-year-old patient with pistol-grip deformity. The triangular index R, or new radius, is pathologic if R ≥ r + 2 mm (estimated magnification, 1.2). An additional parameter for quantification of the femoral head-neck junction is the α angle. R = radius of the femoral head; H = perpendicular line; r = radius of the spherical portion of the femoral head.

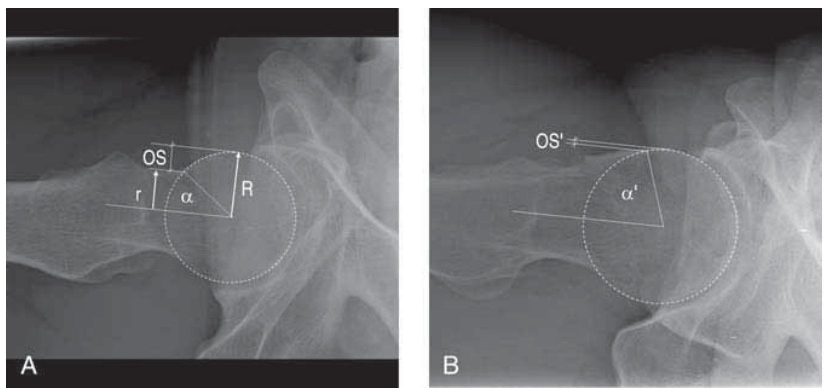

Figure 14 On a cross-table lateral radiograph, the asphericity can be quantified by the α angle, the femoral offset (OS), and the offset ratio. r = radius of the spherical portion of the femoral head; R = increased radius of the femoral head in the aspherical portion. **A,** Normal hip. **B,** Hip with cam impingement.

Angular Deformities of the Proximal Femur

Other causes of cam impingement are femoral retrotorsion and coxa vara. Femoral retrotorsion can occur as primary pathology or in association with malunited femoral neck fractures. To accurately determine torsion of the femur, CT imaging studies are recommended. Coxa vara (defined by a caput collum diaphyseal angle of less than 125°) also can cause impingement. Although in these two pathologies the femoral offset might be normal, the femoral head-neck junction is closer to the acetabular rim during normal activities of daily living, leading to cam impingement.

Secondary Changes in Cam Impingement

As with pincer impingement, labral ossifications can occur in cam impingment. The differential diagnosis of this ossification is hydroxyapatite deposition in the labrum. This calcification is usually resolved on follow-up radiographs at 6 weeks; with FAI (caused by the recurrent contact between the acetabular rim and femoral head-neck junction), labral radiodensity continues.

The recurrent irritation of the acetabular rim by the aspherical portion of the femoral head can cause stress fractures of the acetabulum (Figure 15, *A*). Because the initial appearance of the hip may be normal on an AP pelvis radiograph, these two damage patterns can be misinterpreted as incidental os acetabuli. However, the presence of a radiodense structure at the edge of the acetabular roof should raise suspicion of FAI.

Hips with FAI have a higher prevalence of herniation pits (Figure 15, *B*), which are believed to be benign.[14] They are radiolucencies surrounded by a sclerotic margin and typically located in the anterosuperior quadrant of the femoral neck. They are thought to be intraosseous ganglia at the femoral zone of FAI. Therefore, hips with these juxta-articular cysts should be considered a joint at risk for FAI rather than one with a benign lesion, but herniation

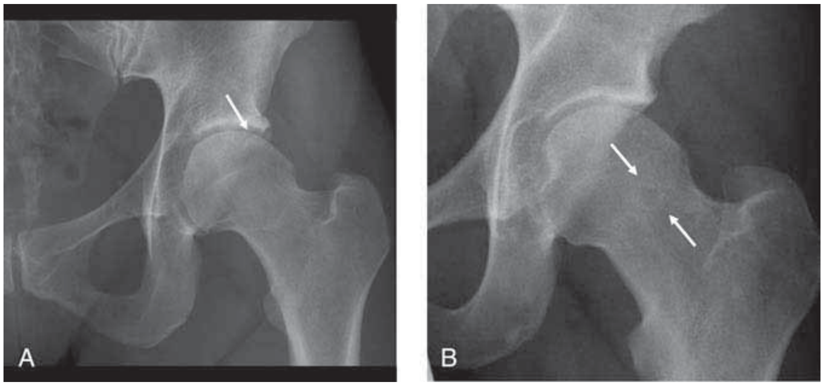

Figure 15 Secondary changes in cam impingement. **A,** Acetabular rim fatigue fractures can occur because of recurrent irritation by the aspherical portion. **B,** Herniation pits can occur in both forms of FAI and are located in the anterosuperior portion of the femoral head.

pits are not always associated with symptomatic impingement. They are usually present long before bone cysts occur in end grade osteoarthritis caused by FAI.

Summary

FAI is a condition of the hip joint that leads to osteoarthritis. Both the pincer and cam types have typical morphologic features on an AP pelvic radiograph and on a mandatory second view of the proximal femur. Despite significant intra-articular damage, classic radiographic signs of osteoarthritis are not present initially. Magnetic resonance arthrography is important for further evaluation of the disease.

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