Appendix

Acetabular Measurements

Acetabular Depth

Acetabular depth can be grossly determined on an anteroposterior pelvic radiograph by assessing the floor of the acetabular fossa or the lateral border of the teardrop, the medial cortex of the femoral head, and their spatial relationship to the ilioischial line. Hips are defined as having *coxa profunda* when the lateral border of the teardrop is in line with or medial to the ilioischial line[5]. When the lateral border of the teardrop and the medial cortex of the femoral head are both medial to the ilioischial line, it is termed acetabular protrusion[5,58]. Some authors have sought to more discretely define profunda on the basis of numerical distances of the acetabular fossa from the ilioischial line. For instance, Armbuster et al.[59] defined *protrusio* as protrusion of the medial wall of the acetabulum from the ilioischial line by 3 mm in men and 6 mm in women. The severity of protrusion was described by Sotelo-Garza and Charnley as mild (1 to 5 mm), moderate (6 to 15 mm), or severe (>15 mm)[60]. Other studies have challenged the clinical implications of isolated coxa profunda, in the absence of other abnormalities[61].

Lateral Center-Edge Angle (LCEA)

An estimation of acetabular coverage of the femoral head can be made with measurement of the LCEA, also called the center-edge angle of Wiberg (Table E-1)[11]. It most specifically defines the superolateral acetabular coverage of the femoral head[12], whereas anterior coverage is best assessed with the anterior center-edge angle, which is measured on a false profile view of the hip or by axial computed tomography (CT). The LCEA is an angle formed by 2 lines. Both lines originate at the center of the femoral head, with 1 line extending superiorly and perpendicular to the transverse axis of the pelvis and the other line passing through the lateral edge of the acetabulum. This latter line was more specifically defined to intersect the most superolateral point of the sclerotic weight-bearing zone of the acetabulum (sourcil)[13]. This refinement to the definition of the LCEA was proposed by Ogata et al.[13], who noted that acetabular retroversion in patients with dysplasia yields an overestimate of the functional lateral coverage with the conventional technique of measuring the LCEA[14]. The Ogata LCEA technique is a more functional method for assessing acetabular coverage as it only includes the weight-bearing portion of the lateral acetabular rim. Utilization of the Wiberg method has been found to overestimate acetabular coverage by an average of 4° because of inclusion of an osseous area that functions as the labral base but does not come into contact with the femoral head, thereby not contributing directly to femoral head coverage[62], which is located posteriorly to the true 12 o'clock position. An LCEA of <25° is associated with inadequate femoral head coverage, and values of >40° are conversely indicative of overcoverage and pincer-type femoroacetabular impingement (FAI)[15,63].

Tönnis Angle

Evaluation of acetabular inclination is one of the most useful and important parameters measured on an anteroposterior pelvic radiograph. The Tönnis angle, also referred to as the sourcil angle, acetabular roof obliquity, and horizontal toit externe (HTE) angle, is the most commonly used measurement for, and broadly classifies, acetabular inclination (Table E-1). The angle is measured by drawing a horizontal line parallel to the transverse pelvic axis, at the most medial edge of the sclerotic sourcil, and then making a second line extending out from the medial edge to the most lateral aspect of the sourcil[15]. This angle classifies acetabular inclination into normal, increased, or decreased categories. A normal Tönnis angle is between 0° and 10°. Generally, >10° denotes structural instability and hip dysplasia, and <0° places the hip at increased risk for pincer-type FAI.

Sourcil Morphology

A normal sourcil has a concave shape that mirrors, and is congruent with, the femoral head. In dysplasia, the sourcil may have a flattened and incongruous shape, creating laterally directed shear forces within the hip joint. The sourcil morphology must be taken into consideration when measuring the LCEA for assessing true functional lateral coverage in cases of suspected instability.

Sharp Angle

Another measurement of acetabular inclination is the Sharp angle (Table E-1)[64]. This angle provides an estimate of total acetabular inclination. This angle is formed with the vertex at the distal point of the acetabular teardrop, with one arm in line with the transverse pelvic axis and the other arm extending out to the superolateral rim of the acetabulum. Angles of ≥45° are associated with acetabular dysplasia.

Roof Length

Klaue et al.[24] described the morphology of some dysplastic acetabuli as having a “short roof,” in which the acetabular weight-bearing zone is short, yet remains congruent with the femoral head. This term has been modified to “flat roof,” as roof length is short in most cases of dysplasia because of the low volume of the acetabulum; however, while many instances have an up-sloping roof with a sourcil angle of >10°, there is a subset with a flat roof[65] that can present with a normal sourcil angle.

Acetabular Version

Acetabular version is associated with hip pathology, with anteversion strongly correlated with developmental dysplasia and retroversion related to pincer-type FAI. However, it is instrumental to understand that the acetabular version, whether assessed on radiographs or CT, is essentially an indication of the relationship between the anterior and posterior walls. The version cannot capture the volume of the socket and, as a result, can give an inaccurate representation in cases of abnormal acetabular volume such as in dysplasia or global overcoverage. Numerous parameters have been proposed to determine acetabular version on anteroposterior pelvic radiographs. Central or equatorial acetabular version refers to the transverse orientation of the acetabular opening in the anterior-posterior direction in relation to the horizontal axis of the pelvis, measured at the center of the femoral head. Normal version has been determined to lie within 13° and 20° anteriorly. Importantly, the pelvic tilt has been shown to substantially impact acetabular version on radiographic imaging[10,66,67]. An increased (or more positive) pelvic tilt will reduce acetabular version, and a decreased (or negative) pelvic tilt may falsely elevate acetabular anteversion. A recent study demonstrated that pelvic tilt decreases when a patient goes from the supine to the standing position and that the true functional, weight-bearing version of the acetabulum may be underrepresented by supine radiographs[16].

Several qualitative signs of acetabular version on an anteroposterior pelvic radiograph have been described in the literature; the crossover sign, posterior wall sign, and ischial spine sign are most commonly utilized (Table E-1)[16,17,68-71]. An anteroposterior pelvic radiograph denotes a positive crossover sign when the contour of the anterior rim lies lateral to the corresponding point of the posterior rim. The presence of a crossover sign, originally described by Reynolds et al. in 1999[17], has been validated by Jamali et al.[68] with a sensitivity and specificity of 96% and 95%, respectively, for determining acetabular retroversion or focal anterosuperior overcoverage. If the posterior rim lies medial to the center of the femoral head, then this denotes either acetabular retroversion or global acetabular dysplasia. It is termed the *posterior wall sign*[17]. If no crossover sign is present, but a posterior wall sign is present, this denotes an overall low-volume socket without versional malalignment[69]. The ischial spine sign is also affected by pelvic tilt, although to a smaller degree than acetabular version[16]. This sign is present on the anteroposterior pelvic radiograph if the ischial spine lies medial to the iliopectineal line[70]. It has been found that, when a crossover sign, posterior wall sign, and ischial spine sign are all present, the abnormality in acetabular morphology is due to global retroversion not associated with posterior wall deficiency or anterior wall overcoverage[69,71].

Quantitatively, there are several methods to calculate acetabular version based on measurements obtained from an anteroposterior pelvic radiograph. The A″-P′-P‴ angle, developed by Jamali et al.[68] as a modification to the original calculation by Meunier et al.[72], has been shown to accurately quantify central acetabular version. Unfortunately, the steps required to arrive at this measurement are cumbersome, diminishing its utility in a clinical setting. As such, Koyama et al.[73] developed the p/a ratio, and Nitschke et al.[74] recently validated 2 new radiographic measures of acetabular anteversion: the transverse axis distance (TAD) and the neck axis distance (NAD)[75], the latter being easily and accurately utilized in the clinical setting. All 3 parameters have been shown to be well correlated with the gold standard of CT acetabular version assessment.

The p/a Ratio

The p/a ratio is calculated first by drawing a line (the bisecting line) between the inferior border of the teardrop and the lateral edge of the acetabulum (Table E-1). The “a” measurement is then made by marking a line from the most medial aspect of the sourcil to a point on the anterior wall that would intersect the bisecting line at a 90° angle. Similarly, the “p” measure is made by creating a line from the most medial aspect of the sourcil to a point on the posterior wall in the same orientation to the bisecting line as “a.” The “p” value is then divided by the “a” value to determine the p/a ratio. If the bisecting line falls within the acetabular fossa, then the point on a best-fit circle of the acetabulum is drawn along the sourcil to yield the point along the acetabular articular surface from which to measure “p” and “a.” In the study population described by Koyama et al., the average p/a ratio was 2.05, with large p/a ratios indicating acetabular anteversion and smaller p/a ratios indicating acetabular retroversion[73]. The conversion equation from the work by Koyama to estimate central version is acetabular version = 9.6 × p/a – 0.3.

Neck Axis Distance (NAD)

Neck axis distance is measured on the anteroposterior pelvic radiograph by first drawing a line (line N) down the axis of the femoral neck that bisects the center of a best-fit circle about the femoral head (Table E-1). The distance between the anterior wall and the posterior wall along line N is then measured. A measurement of ≥14 mm is associated with excessive anteversion (with a sensitivity of 0.76 and specificity of 0.78)[75].

Joint Space and Hip Center

The area between the acetabulum and the margin of the femoral head is known as the joint space (Table E-1). Side-to-side differences in joint-space width (JSW) and the minimal JSW value can provide useful clues regarding pathology. The minimal JSW is the measured distance from the femoral head margin to the nearest weight-bearing surface of the acetabulum (along the sourcil)[42]. Other important areas in which the JSW is measured are the lateral and medial borders of the weight-bearing surface and the apex of the sourcil. Normal JSW values are significantly higher in men and are generally largest at the lateral measurement and smallest at the apex of the sourcil[76-79]. Reduction in JSW is synonymous with cartilage loss and thereby a sensitive sign for the early development of osteoarthritis in the hip. Interestingly, patients with hip dysplasia as measured by the LCEA have been shown to have significantly increased cartilage thickness and thereby increased JSW compared with their normal morphologic counterparts[21]. A JSW of <2 mm has been implicated in numerous studies with worse outcomes in hip preservation surgery[48,51]. The position of the hip center can also be evaluated by looking at the relative joint space. It can be classified as lateralized or not lateralized on the basis of the position of the medial aspect of the femoral head in relation to the ilioischial line. If this measurement is ≤10 mm, the hip center is considered not to be lateralized[5].

Acetabular Quotient

The acetabular quotient assesses the relationship of the depth of the acetabulum to its width (Table E-1). It is determined by dividing the width of the acetabulum, measured as the distance from inferior teardrop to the lateral rim, by the depth of the acetabulum, measured from a perpendicular line started at the midpoint of the width line to the acetabular dome. This value is then multiplied by 1,000[80]. A value of <250 denotes an abnormally shallow hip socket, consistent with hip dysplasia. This quotient is a modification of the Heyman and Herndon acetabular index of depth to width[19].

Shenton Line

The Shenton line is a commonly used qualitative radiographic marker of acetabular dysplasia (Table E-1)[81]. It is defined as an unbroken arch formed by the top of the obturator foramen and the inner side of the femoral neck. The Shenton line is determined to be broken if the inferior femoral neck projection is cephalad to the superior arch of the obturator foramen. A break in the Shenton line is indicative of more severe forms of acetabular dysplasia with a superolateral hip center, whereas a continuous line does not exclude an unstable hip.

Iliofemoral Line

The iliofemoral line (IFL) is defined as the smooth line extending from the apex of the concavity of the lateral aspect of the femoral neck through the inner cortical lip of the ilium on an anteroposterior pelvic radiograph (Table E-1)[82]. The percent medialization of the iliofemoral line is defined as the horizontal distance of the exposed femoral head lateral to the IFL relative to the horizontal femoral head width at the center of the femoral head.

Femoral Measurements

Neck-Shaft Angle (NSA)

The femoral neck-shaft angle depicts where in the coronal plane the femoral head lies in relation to the anatomic axis of the femur (Table E-2). The apex of the angle lies at the intertrochanteric line and is at the intersection of a line going down the medullary canal of the femur and a second line parallel to the neck of the proximal part of the femur. A normal NSA is between 120° and 140°, with an NSA of >140° referred to as coxa valga and <120° termed coxa vara[79,83,84]. Coxa valga and increased external femoral torsion (anteversion), which often presents itself on an anteroposterior pelvic radiograph as coxa valga, are found in higher frequency in patients with hip dysplasia[85,86.] In contrast, coxa vara is more commonly associated with FAI[87,88].

The α Angle

On an anteroposterior pelvic radiograph, the α angle is measured by drawing a circle collinear with the curvature of the femoral head (Table E-2). The apex of the angle is at the center of the femoral head (circle center), with 1 arm going down the shaft of the femoral neck and the other arm extending to the location where the bump comes out of round from the femoral head. An α angle of >50° to 55° is indicative of an abnormal head-neck contour, indicating (lateral) cam-type FAI[18]. A normal femoral head-neck offset during standard hip range of motion will allow the femoral head to rotate within the acetabulum without osseous or soft-tissue impingement. However, in cam-type FAI, a bump exists on the head-neck junction that can create an osseous conflict with the acetabular rim and alter hip biomechanics and can be assessed on radiographs. Most commonly these bumps occur on the anterosuperior or anterolateral aspect of the femoral head-neck junction. On an anteroposterior pelvic radiograph, an anterolateral or cam-type deformity at 12 to 1 o’clock can be measured and is often called a pistol-grip deformity[39]. If the hip is internally rotated when the radiograph is made, more posterior cam lesions (extending posteriorly from 12 o’clock) can be seen. Given the dependence on hip position, the α angle must be reported in conjunction with the radiographic view used to make the measurement in order to give both the size and location of the cam lesion.

Head-Neck Offset and Ratio

Another way to assess the head-neck junction is to measure the head-neck offset or ratio (Table E-2). Offset is defined as the difference between the radius of the femoral head and the femoral neck. It is measured as the distance between the outermost portion of the femoral neck and the exit point of the femoral neck or cam lesion, if one exists. Normal offset is >9 mm[5]. The offset ratio can then be calculated by taking the measure of the offset and dividing it by the diameter of the femoral head, with <0.18 being pathologic[89].

Articulotrochanteric Distance (ATD)

The distance between the superior tip of the greater trochanter and the highest point of the articular surface of the femoral head is called the articulotrochanteric distance (ATD) (Table E-2)[90]. This distance is measured by making a line parallel to the femoral shaft and then drawing a perpendicular line at the tip of the greater trochanter and another at the superior aspect of the femoral head. If the tip of the greater trochanter is distal to the superior margin of the femoral head, then the ATD is positive. Conversely, if the greater trochanter is superior to the upper portion of the femoral head, the ATD is negative. The ATD correlates with coxa valga and coxa plana[91] and can also affect portal placement during hip arthroscopy.

Femoral Head Extrusion Index

A more complex, but very useful, quantification of acetabular coverage is called the femoral head extrusion index (FHEI) and is the percentage of the femoral head not covered by the acetabulum (Table E-2)[19]. This percentage is calculated by measuring the width of the femoral head that lies lateral to the lateral extent of the acetabulum (A), dividing it by the total horizontal width of the covered femoral head (B), and multiplying by 100 ([A/B] × 100). A normal hip has an extrusion index of <25%. Similar to this measurement is “femoral head coverage,” which measures the distance between the medial cortex of the femoral head and the lateral acetabular rim and divides it by the diameter of the femoral head. In this calculation, <75% is pathologic[80,92] and indicates undercoverage or potential dysplasia.

The Pelvic Ring and Lower Spine

An anteroposterior pelvic radiograph can also provide clues to pathology outside the hip that can be sources of pain in this area. The lower lumbar and sacral spine are well visualized in this single view, and assessment for degenerative changes, such as osteophyte formation, disc degeneration, and scoliosis, can be performed. Any evidence of lower lumbar malformation, for example, spina bifida occulta or lumbar sacralization, can also be appreciated (Fig. E-1). Bridging syndesmophytes between lumbar vertebrae and bilateral sacroiliitis, sclerosis, or frank fusion of the sacroiliac joints are evidence of ankylosing spondylitis. Asymmetric sacroiliitis may be an indicator of other seronegative spondyloarthropathies such as psoriasis and Reiter disease[93].

The joint at the anterior aspect of the pelvic ring, the pubic symphysis, can also be an etiology of pain in isolation or concomitantly with other pathology. In a correctly made anteroposterior pelvic radiograph, this joint is visually discrete. In addition to the patient’s presenting symptoms and examination, irregularities at the pubic symphysis on imaging should raise concern. Subchondral erosive changes, joint irregularity, sclerosis, and/or diastasis at the pubic symphysis could be the result of osteitis pubis, osteomyelitis, ligamentous laxity in pregnancy, or prior trauma to the pelvic ring (Fig. E-2)[94,95]. Osteitis pubis has been found to frequently co-occur in patients with cam-type FAI[96]. Male collegiate athletes in the National Football League Scouting Combine were found to commonly have both radiographic evidence of FAI and osteitis pubis[97].

There are also multiple protuberances about the pelvis that are formed because of the origin of muscles at these locations. The anterior superior iliac spine (ASIS) is the origin of the sartorius, the rectus femoris originates at the anterior inferior iliac spine (AIIS), and the ischial tuberosity is the origin of the semimembranosus, biceps femoris, and semitendinosus. As such, these areas can be the site of avulsion fracture injuries and may be visualized on standard anteroposterior pelvic radiography (Figs. E-3A and E-3B). In the skeletally immature, this may manifest as apophysitis rather than frank fracture. Any calcifications about the ischial tuberosities, ASIS, and AIIS can also indicate a picture of chronic tendinosis (Fig. E-3C).

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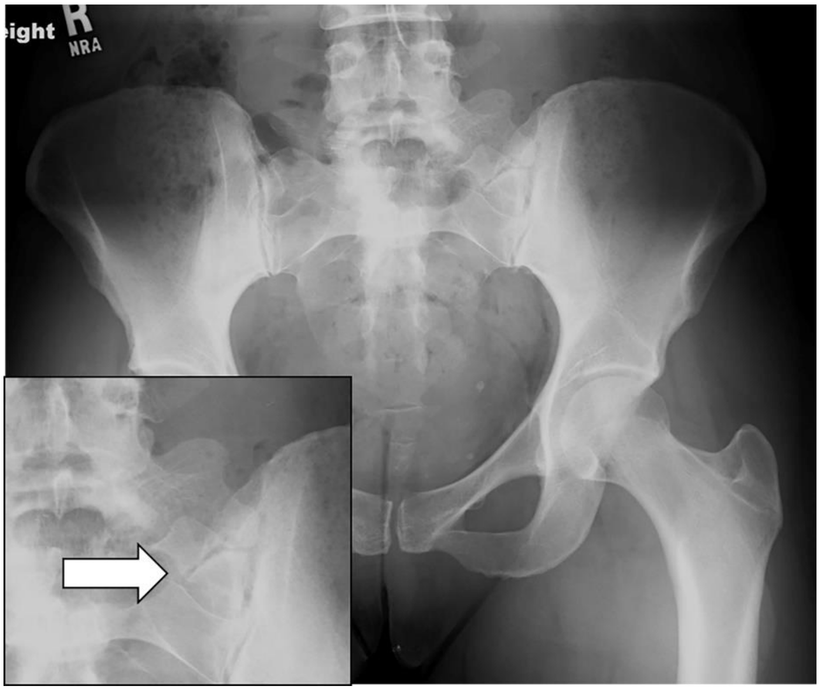


Fig. E-1
Anteroposterior radiograph of the pelvis depicts transitional segmentation of the lumbosacral spine with a hypertrophied L5 transverse process and degenerative pseudarthrosis on the left (arrow in insert).

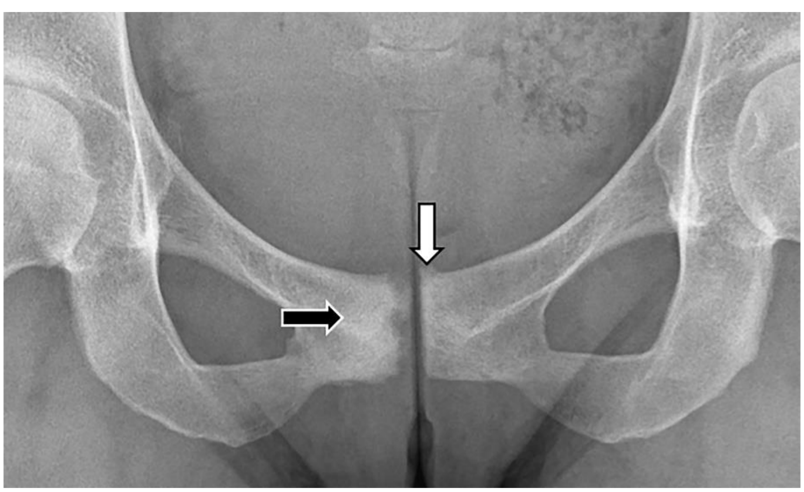


Fig. E-2
Anteroposterior pelvic radiograph showing sclerosis (black arrow) and osteophyte formation (white arrow), which are common findings associated with osteitis pubis.

http://dx.doi.org/10.2106/JBJS.17.00500

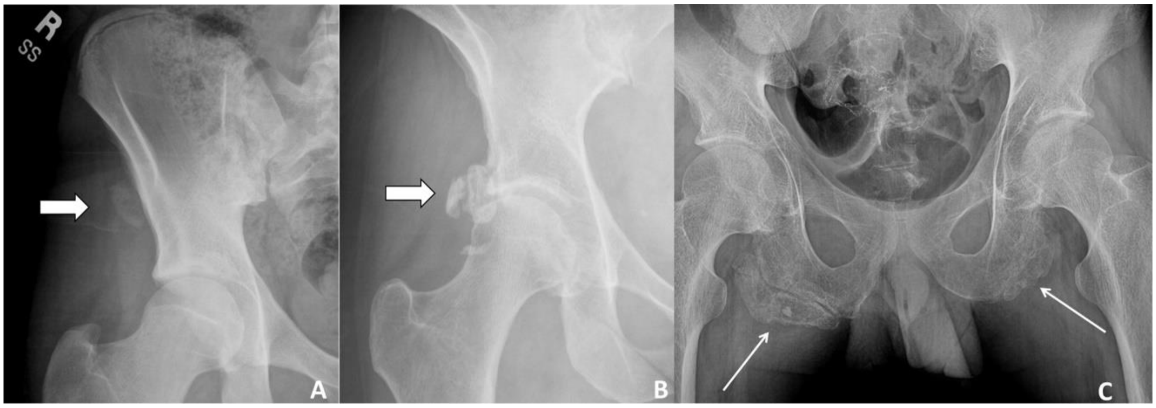
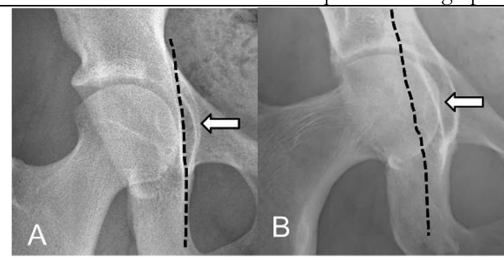
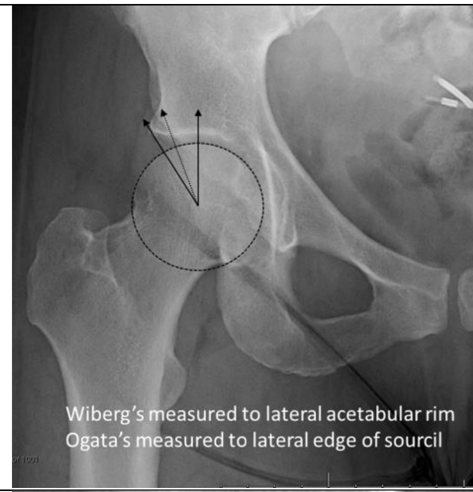
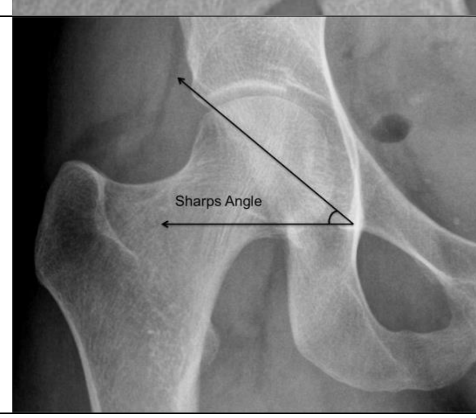


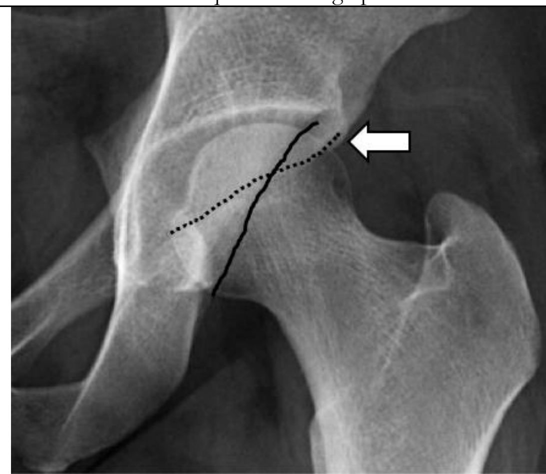
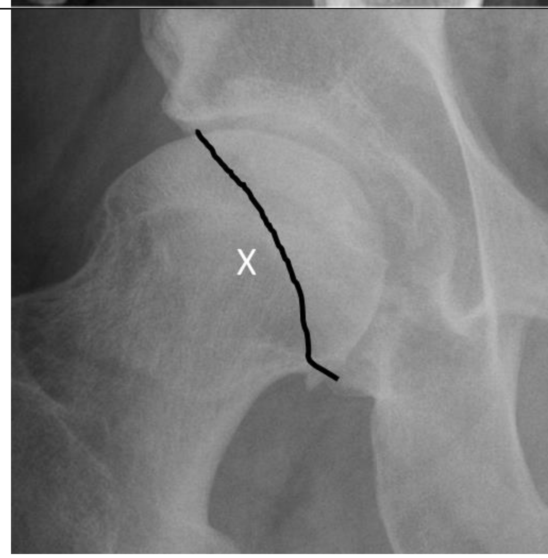
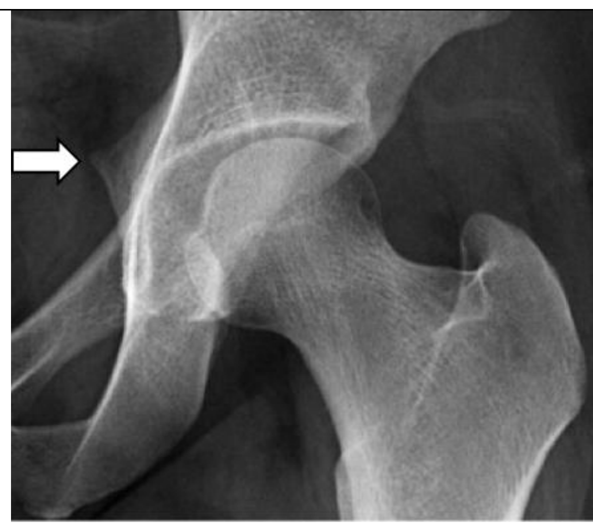
Fig. E-3

Figs. E-3A, E-3B, and E-3C Radiographs showing pathology about the pelvis. **Fig. E-3A** Anteroposterior radiograph of the right hip showing a subtle cortical avulsion fragment (arrow) inferiorly distracted from the ASIS, which is compatible with sartorius ASIS avulsion. **Fig. E-3B** Anteroposterior radiograph of the right hip demonstrating remote AIIS avulsion injury (arrow). **Fig. E-3C** Anteroposterior pelvic radiograph demonstrating extensive bone proliferation and enthesopathy at the ischial tuberosity bilaterally (arrows), which is compatible with chronic hamstring tendinosis.

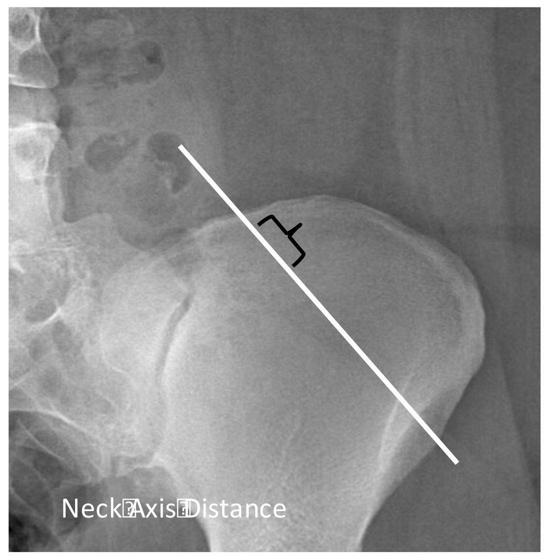
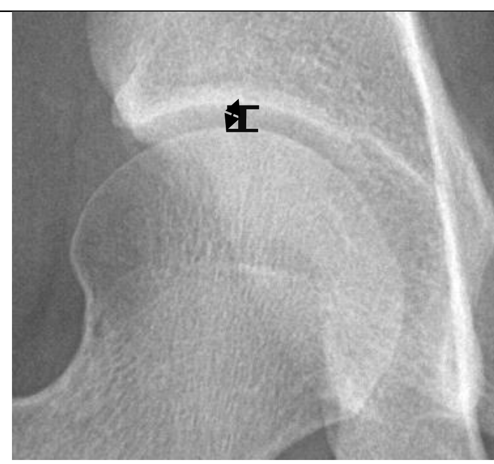
TABLE E-1 Acetabular Signs and Measurements on an Anteroposterior Pelvic Radiograph

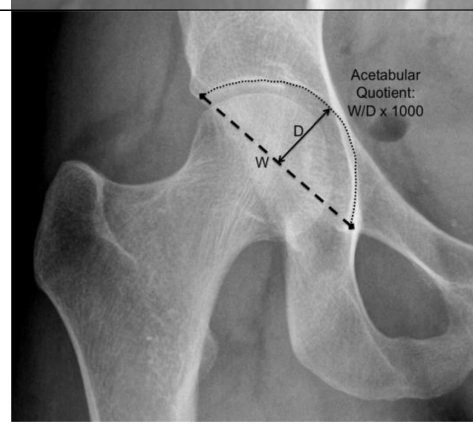
Measurement	Normal	Pathologic	Measurement Technique on Radiograph
Acetabular depth[5,58]*		A: Coxa profunda B: Acetabular protrusio	
Lateral center-edge angle[11]* 1. Wiberg 2. Ogata	25° - 40°	<25° or >40°	
Tönnis angle[15]*	0° - 10°	<0° or >10°	
Sharp angle[64]*	<45°	>45° suggests dysplasia	

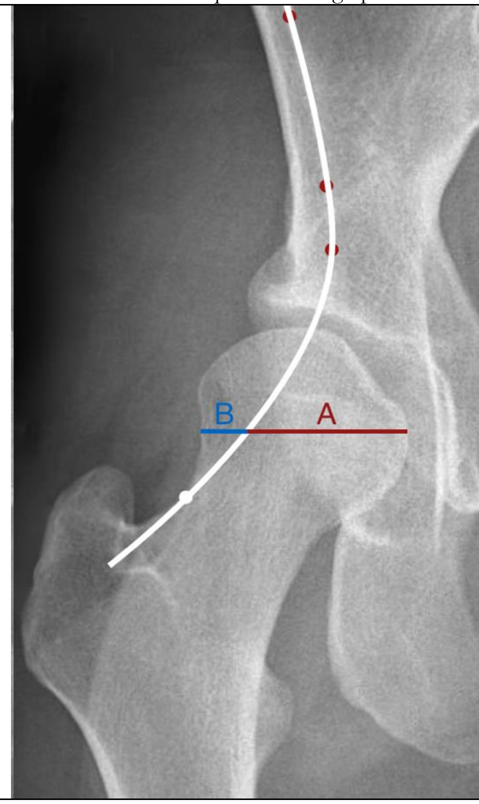
http://dx.doi.org/10.2106/JBJS.17.00500

Measurement	Normal	Pathologic	Measurement Technique on Radiograph
Crossover sign[17]	Not present	Present	
Posterior wall sign[17]	Not present	Present	
Ischial spine sign[16]	Not present	Present	

http://dx.doi.org/10.2106/JBJS.17.00500

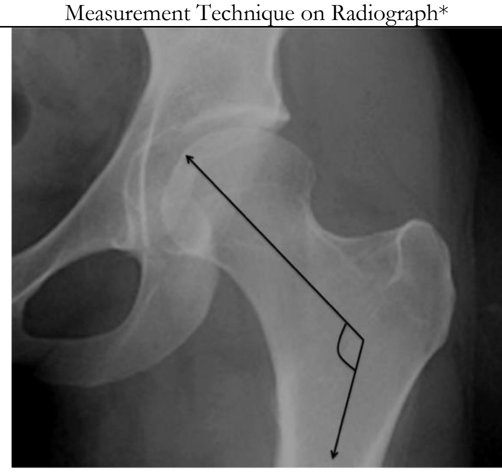
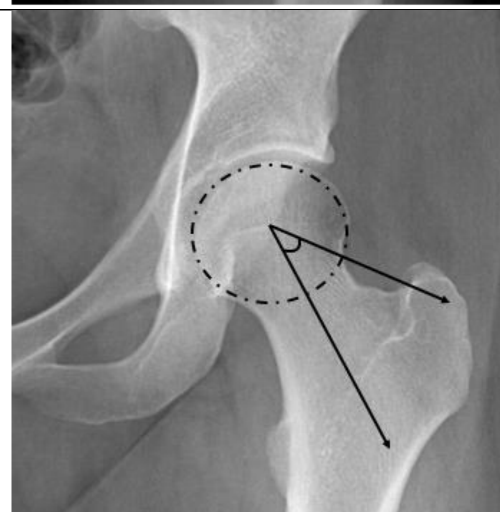
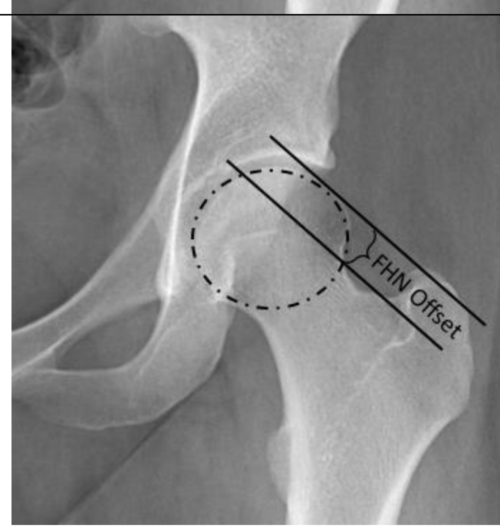
Measurement	Normal	Pathologic	Measurement Technique on Radiograph
The p/a ratio[73]	2.05		
Neck axis distance[75]	<14 mm		
Joint-space width[42]			

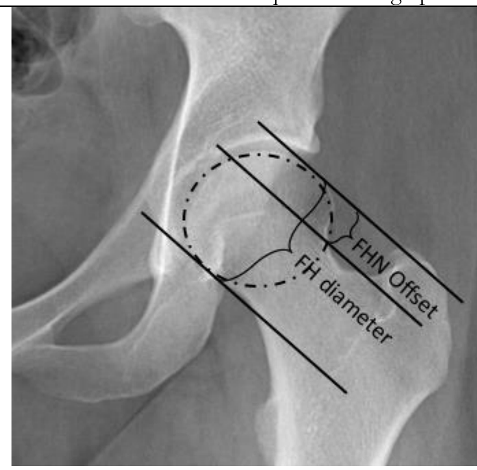
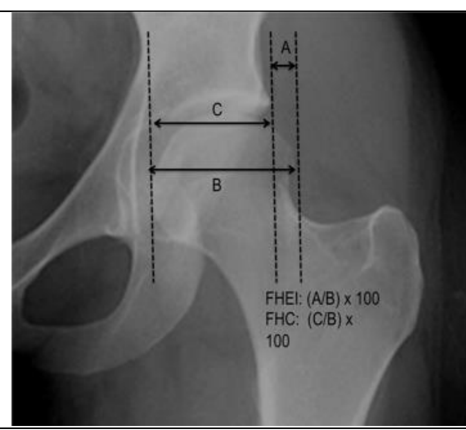
Measurement	Normal	Pathologic	Measurement Technique on Radiograph
Hip center[5]	<10 mm	>10 mm	
Acetabular quotient[80]	>250	<250	
Shenton line[81]	Congruent line	>5 mm break	

Measurement	Normal	Pathologic	Measurement Technique on Radiograph
Iliofemoral line[82]	<15%	>15%	

*The images showing the acetabular depth, lateral center-edge angle, Tönnis angle, and Sharp angle measurements are reproduced, with permission, from: Jesse MK, Petersen B, Strickland C, Mei-Dan O. Normal anatomy and imaging of the hip: emphasis on impingement assessment. Semin Musculoskelet Radiol. 2013 Jul;17(3):229-47. ©Georg Thieme Verlag KG.

TABLE E-2 Femoral Parameters Measured on an Anteroposterior Pelvic Radiograph

Measurement	Normal	Pathologic	Measurement Technique on Radiograph*
Neck-shaft angle[79]	120° - 140°	<120° or >140°	
α angle[18]	<50° - 55°	>50° - 55°	
Head-neck offset[5]*	>9 mm	<9 mm	

Measurement	Normal	Pathologic	Measurement Technique on Radiograph
Head-neck offset ratio[89]*	>0.18	<0.18	
Articulotrochanteric distance (ATD)[90]	Positive number	Negative number	
Femoral head extrusion index (FHEI)[19]*†	<25%	>25%	

*FHN = femoral head-neck, FH = femoral head, and FHC = femoral head center. †Femoral head extrusion index (FHEI) image reproduced, with permission, from: Jesse MK, Petersen B, Strickland C, Mei-Dan O. Normal anatomy and imaging of the hip: emphasis on impingement assessment. Semin Musculoskelet Radiol. 2013 Jul;17(3):229-47. ©Georg Thieme Verlag KG.