Imaging Evaluation of Developmental Hip Dysplasia in the Young Adult

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OBJECTIVE. The purpose of this article is to review the clinical and imaging features as well as the potential complications of hip dysplasia in the young adult. Hip dysplasia is an important cause of secondary osteoarthrosis, which accounts for a significant proportion of patients requiring total hip arthroplasty. The radiographic diagnosis of mild hip dysplasia in the young adult may be subtle and is primarily based on the detection of deficient coverage of the femoral head by the acetabulum.

CONCLUSION. Cross-sectional imaging, including CT and MRI, afford improved detection and characterization by providing morphologic information about acetabular deficiency. MRI also allows evaluation of potential associated injuries to the articular cartilage, the labrum, and the ligamentum teres. Familiarity with the radiographic and cross-sectional imaging findings of mild hip dysplasia in the young adult may allow a timely diagnosis and implementation of treatment strategies, which may prevent or delay the development of early osteoarthritis.

Developmental dysplasia of the hip encompasses a wide spectrum of hip abnormality, ranging from a shallow acetabulum to a completely dislocated “high-riding” hip. The diagnosis of developmental hip dysplasia can be obvious but may sometimes be subtle, with a normally shaped femoral head and neck that simply lack sufficient coverage by the acetabulum. Despite attempts at early diagnosis by screening at birth and during infancy for hip dysplasia, a relatively significant number of cases go undetected until adulthood, with an estimated prevalence of 0.1% [1]. The delayed diagnosis and lack of early intervention can lead to early osteoarthrosis in the young adult [2–5].

The natural history of developmental dysplasia of the hip has been well evaluated in the literature [2, 6] and has been noted to lead to the development of osteoarthrosis in 25–50% of patients by the age of 50.3 years. More specifically, Wiberg [5] in his studies of congenital subluxation of the hip noted that all of his patients with definite subluxation showed osteoarthrosis by the age of 50–60 years. Wedge and Wasylenko [4] indicated that, in general, patients with developmental dysplasia develop coxarthrosis about 10 years later than those with subluxation. Additionally, increased femoral anteversion and acetabular dysplasia have been implicated as causative factors in “primary” or “idiopathic” osteoarthrosis of the hips [7].

Wedge and Wasylenko [4] on the basis of a consensus of the literature showed that if concentric reduction and normal function are achieved before 1 year of age, femoral anteverision and acetabular dysplasia improve spontaneously. Before 4 years of age, concentric reduction plus correction of either the anteverision or the acetabular dysplasia result in improvement of the other. After the age of 4 years, spontaneous improvement is unlikely, and concentric reduction must be accompanied by surgical correction for secondary deformity on both sides of the joint [4]. It is generally accepted that if developmental dysplasia of the hip is recognized early, correction of the deranged anatomy must be undergone to prevent coxarthrosis [4]. Even in mild hip dysplasia, the relative lateralization of the hip center of rotation, the poor coverage of the femoral head, and the smaller contact area between the femoral head and acetabular dysplasia can produce highly asymmetric concentration of force across the hip joint (Fig. 1) and secondary articular cartilage and labral damage [8–10].

Treatment of adult hip dysplasia is aimed at prolonging longevity of the joint by performing periacetabular osteotomy, femoral varus osteotomy, or both early in the course of the...
disease. Hip joint replacement is required in patients who develop severe arthrosis.

Hip replacement options include standard total hip replacement and hip resurfacing arthroplasty. The long-term problem with total hip replacement is failure resulting in revision surgery. Failure of total hip replacement is often caused by aseptic loosening secondary to polyethylene wear [11] or dislocation of the prosthesis [12]. Hip resurfacing arthroplasty has been advocated because it uses alternative bearing surfaces that have lower wear and allow larger femoral head sizes. In theory, hip resurfacing arthroplasty when compared with conventional total hip replacement has better preservation of bone stock (less bone removal), fewer dislocations attributed to a larger femoral head size, and easier revision surgery to a total hip replacement given greater availability of bone stock [13]. Hence, hip resurfacing arthroplasty may present a better alternative for younger patients in whom life expectancy after implantation is long.

Nevertheless, a recent study [14] showed that 6.2% of metal-on-metal hip implants had failed within 5 years, compared with 1.7% of metal-on-plastic and 2.3% of ceramic-on-ceramic hip implants. Furthermore, larger, rather than lower, femoral head sizes in metal-on-metal hip resurfacing articulations increase implant failure rates, with each 1-mm increase in head size of metal-on-metal hip implants being associated with a 2% increase in failure. This study has led to a reevaluation of metal-on-metal hip resurfacing arthroplasty. In particular, the United States Food and Drug Administration (FDA) issued a patient advisory on metal-on-metal hip implants and established an advisory panel 2-day meeting in June 2012 [15], recommending that evaluation of patients for adverse effects associated with a metal-on-metal hip implant should include an expedited physical examination with an orthopedic surgeon, routine radiography, and both standard and metal (cobalt and chromium) titers in blood tests.

A significant number of hip arthroplasties are performed for the treatment of developmental dysplasia of the hip with superimposed arthrosis. A recent study by Engesaeter et al. [16] performed in patients younger than 44 years found that 26% of 634 hip replacements were performed for the treatment of osteoarthritis secondary to hip dysplasia. Several authors have shown that the number of patients requiring hip replacement may be modified by early diagnosis and treatment of this condition. In particular, a study performed by Takatori et al. [17] evaluated the results of rotational acetabular osteotomies in 13 severely dysplastic hips with subluxation in 11 young women between 20 and 35 years old at the time of surgery. At a minimum follow-up period of 10 years, the patients had minimal or no pain and of the 13 hips, 12 showed no significant findings of osteoarthrosis. Comparing the outcome of these patients with the natural evolution of severely dysplastic hips, the authors concluded that rotational acetabular osteotomy may prevent the onset of articular cartilage damage.

A study by Badra et al. [18] assessed the functional outcome of a group of adult patients after Bernese periacetabular osteotomy in 24 patients with mean follow-up of 3.5 years. They found that 75% of their patients had good to excellent results. Even patients with radiographic evidence of mild coxarthrosis benefited from Bernese periacetabular osteotomy, with good to excellent results seen in 75% of patients having Tonnis osteoarthrosis grade 1 and 81.8% of patients having Tonnis osteoarthrosis grade 2, delaying or eliminating the need for total hip arthroplasty. However, a trend toward a poorer outcome was observed in patients with preoperative noncongruent joints and Tonnis osteoarthrosis grade 3.

The radiographic diagnosis of hip dysplasia in the young adult may be subtle. Cross-sectional imaging of hip dysplasia, including CT and MRI, can provide additional morphologic information that may improve detection and characterization of acetabular deficiency. MRI can also assess the hip joint for potential associated injuries to the articular cartilage, labrum, and the ligamentum teres. In this article, we discuss the morphologic features of hip dysplasia, the radiographic and cross-sectional imaging features of acetabular coverage, and the complications of hip dysplasia. In addition, less-well-recognized features in hip dysplasia, including abnormalities of the ligamentum teres and labral abnormality, are also discussed.

**Imaging of Hip Dysplasia in the Young Adult**

**Radiographic Evaluation**

The diagnosis of hip dysplasia has traditionally been based on radiographic evaluation. The most commonly used measurements of hip dysplasia are the center-edge angle, vertical-center-anterior margin angle, and acetabular index angle, which provide information on acetabular deficiency, and the caput collum diaphysis angle, which focuses on the femoral head-neck-shaft relationship. Radiography has been used as the mainstay for diagnosis in hip dysplasia and has certain advantages, such as lower cost and better accessibility, compared with CT and MRI; however, radiography lacks...
sensitivity for assessing early coxarthrosis. Furthermore, significant measurement errors may occur on radiographs due to suboptimal patient positioning and difficulties in identifying the exact osseous landmarks in patients with hip dysplasia. Additionally, the imaging evaluation provided by radiographic methods lacks the 3D information obtained with cross-sectional imaging and thus limits accurate quantification of the degree and location of abnormalities in the hip joint articular surfaces.

**Center-Edge Angle and Vertical-Center-Anterior Margin Angle**

The diagnosis of hip dysplasia can be made with a center-edge angle of Wiberg of less than 20° measured on a well-centered anteroposterior radiograph of the pelvis (Table 1 and Fig. 2). A center-edge angle value greater than 25° is normal [5]. Values of 20–25° are considered borderline dysplasia and describe patients who are at the lower limits of normal in terms of coverage of the femoral head but not quite considered to have uncovering [5].

The anteroposterior radiograph of the pelvis should be obtained with the patient supine on the table with both lower extremities oriented in 15° of internal rotation to maximize the length of the femoral neck [19]. The x-ray tube-to-film distance should be 120 cm, with the tube oriented perpendicular to the table [19]. The crosshairs of the beam should be centered on the point midway between the superior border of the pubic symphysis and a line drawn connecting the anterior superior iliac spines [19]. Stulberg and Harris [20] reported that the average center-edge angle of 60 normal patients was 37° in men and 35° in women.

Reliable measurements of the center-edge angle have been reported on the basis of both 3D CT [21] and MRI [22] assessment of the hip. A refined version of the classic Wiberg center-edge angle on the pelvis radiograph was proposed by Ogata et al. [23] when they observed that, in some hips that had a normal Wiberg center-edge angle, the lateral point of osseous condensation of the acetabular roof did not reach the lateral rim of the acetabular roof.

**TABLE 1: Radiographic Measurements of Developmental Dysplasia of the Hip**

<table>
<thead>
<tr>
<th>Measurement</th>
<th>Technique</th>
<th>Description</th>
<th>Normal vs Abnormal Values</th>
<th>Example Figure</th>
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<tbody>
<tr>
<td>Center-edge angle</td>
<td>Anteroposterior pelvis radiography</td>
<td>Angle between vertical line through femoral head center and line tangential to lateral margin of acetabulum</td>
<td>Normal &gt; 25°</td>
<td>2</td>
</tr>
<tr>
<td>Vertical-center-anterior margin angle</td>
<td>Lateral “false profile” radiography</td>
<td>Angle between vertical line through femoral head center and anterior margin of acetabulum</td>
<td>Normal &gt; 25°</td>
<td>3</td>
</tr>
<tr>
<td>Femoral head-neck-shaft angle</td>
<td>Anteroposterior pelvis radiography</td>
<td>Angle between line through femoral head center along axis of femoral neck and intersecting line drawn along femoral shaft axis</td>
<td>Normal 120–135°</td>
<td>4</td>
</tr>
<tr>
<td>Tonnis angle</td>
<td>Anteroposterior pelvis radiography</td>
<td>Angle between horizontal line at level of medial edge of sourcil and line tangential to medial and lateral edges of sourcil</td>
<td>Normal ≤ 13°</td>
<td>5</td>
</tr>
<tr>
<td>Delta angle</td>
<td>Anteroposterior pelvis radiography</td>
<td>Angle between lines drawn through medial edge of sourcil and superior edge of fovea capitis through femoral head center</td>
<td>Normal &gt; 10°</td>
<td>6</td>
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**Fig. 2**—Measurement of center-edge angle.

A. Drawing shows center-edge angle (CEA), which is measured by drawing line through center of both femoral heads on well-centered anteroposterior pelvis radiograph perpendicular line in femoral head of interest and line through lateral margin of acetabulum and femoral head. Angle formed between perpendicular and lateral margin of acetabulum is CEA.

B. Anteroposterior pelvis radiograph in 38-year-old woman shows dysplastic left hip (CEA < 20°).
and poor acetabular coverage developed later. They stated that the classic center-edge angle was not reliable in these hips, and they modified the center-edge angle measurement method to account for this factor by measuring the center-edge angle at the lateral point of osseous condensation of the acetabular roof when that point did not reach the lateral rim of the acetabular roof. Omeroglu et al. [24] subsequently evaluated the intraobserver variability and interobserver variability of the classic Wiberg center-edge angle method and the refined Ogata method. They reported an average intraobserver variation of 3.1 ± 3.0° (range, 0°–17°) for the classic center-edge angle and 3.8 ± 2.8° (range, 0°–17°) for the refined center-edge angle (Student t test, \( p = 0.02 \)). Average interobserver variation was 4.0 ± 3.6° (range, 0°–26°) for the classic center-edge angle and 5.1 ± 4.8° (range, 0°–26°) for the refined center-edge angle (Student t test, \( p < 0.001 \)). They attributed the nearly 1° less intraobserver and interobserver variability in the classic center-edge angle method compared with the refined center-edge angle method to easier determination of the most lateral point of the acetabular roof used by the classic method than that of the osseous condensation used by the refined method. However, they pointed out that although the classic center-edge angle measurement may have less intraobserver and interobserver variability, it carries the risk of radiographic overestimation of the lateral femoral head coverage in some cases. Nevertheless, the center-edge angle measurement of Wiberg remains the most used measurement and is included in most radiographic classifications of hip dysplasia [25].

A vertical-center-anterior margin angle, also known as anterior-center-edge angle, evaluates for anterior coverage of the femoral head by the acetabulum (Table 1 and Fig. 3). The vertical-center-anterior margin is measured on a lateral or “false-profile” view (Fig. 3) of the hip as the angle formed between a vertical line through the center of the femoral head and a line tangential to the anterior margin of the acetabular roof. Normal anterior acetabular coverage is present when the vertical-center-anterior margin is greater than 20°. A vertical-center-anterior margin measuring less than 20° is considered diagnostic of hip dysplasia. Vertical-center-anterior margin measurements between 20° and 25° are representative of borderline dysplasia [26–28]. The interobserver reproducibility of the vertical-center-anterior margin radiographic measurement has been reported to be satisfactory on the basis of the intraclass coefficient (ICC) of 0.83 (95% CI, 0.72–0.90) [29]. However, the kappa coefficient of 0.41 (95% CI, 0.07–0.74) indicates only moderate reproducibility [29].

The false-profile radiograph is obtained with the patient in a standing position with the affected hip against the cassette and the pelvis rotated 65° in relation to the Bucky wall stand (Fig. 3) [19]. The foot on the same side as the affected hip should be positioned so that it is parallel to the cassette [19]. The central beam is then centered on the femoral head, with a tube-to-film distance of approximately 102 cm [19].

Femoral Head-Neck-Shaft Angle

The femoral head-neck-shaft angle, or caput collum diaphysis angle, is measured at the intersection of the femoral neck axis with the long axis of the femoral shaft (Table 1 and Fig. 4). Normal values for the caput collum diaphysis angle in adults range from 120° to 135°. An increased caput collum diaphysis angle greater than 135° is diagnostic of coxa valga, whereas a decreased caput collum diaphysis angle of less than 120° is consistent with coxa vara [30]. Although hip dysplasia may be associated with coxa valga, patients with hip dysplasia may have a normal caput collum diaphysis angle or, less commonly, coxa vara; therefore, the caput collum diaphysis angle is of limited value as a diagnostic marker. However, the caput collum diaphysis angle is of clinical importance because it may affect the treatment decision and surgical planning. A study by Clohisy et al. [31] indicated that in their research of 108 dysplastic hips, which were corrected with periacetabular osteotomy, 44% had coxa valga and 4% had coxa vara. They concluded that identifying and treating these proximal femoral abnormalities in patients with acetabular dysplasia may optimize joint congruency and minimize secondary impingement after acetabular reorientation. Measurements of the caput collum diaphysis angle should be performed on a true anteroposterior view of the hip; external rotation of the femur may simulate a coxa valga deformity. Similarly, femoral anteversion may produce a false appearance of coxa valga deformity. Therefore, when an increased caput collum diaphysis angle is encountered on radiographs, it is probably better to use the term “apparent coxa valga,” particularly if the hip is suboptimally positioned. The interobserver reproducibility of...
Fig. 4—Measurement of femoral head-neck-shaft or caput collum diaphysis (CCD).  
A, Drawing shows femoral head-neck-shaft or caput collum diaphysis (CCD) angle formed by line extending through center of femoral head along axis of femoral neck with intersecting line drawn along axis of femoral shaft. 
B and C, Anteroposterior pelvis radiographs in 32-year-old man (B) with mild left and moderate right hip dysplasia and coxa valga (CCD > 135°) with CCD measurement shown for left hip and 39-year-old man (C) with severe bilateral hip dysplasia with dislocated hips and coxa vara (CCD < 120°) with CCD measurement shown for left hip.

Fig. 5—Measurement of weightbearing acetabular index (Tonnis angle).  
A, Drawing shows measurement of weightbearing acetabular index (Tonnis angle) or horizontal toit externe angle, formed by angle between horizontal line at level of medial edge of sourcil and line tangential to medial and lateral edges of sourcil. 
B, Anteroposterior pelvis radiograph cropped and magnified to right hip in 32-year-old man shows dysplastic hip with horizontal toit externe angle > 13°.
the caput collum diaphysis radiographic measurement has been reported to be satisfactory on the basis of the ICC of 0.83 (95% CI, 0.72–0.90) and a kappa coefficient of 1.00 (95% CI, 1–1), indicating almost perfect reproducibility [29].

Acetabular Index

The weightbearing acetabular index (Tonnis angle), or horizontal toit externe angle, measures the weightbearing surface of the acetabulum or sourcil. More precisely, the sourcil represents an area of subchondral osseous condensation in the acetabular roof, which is a response by the articular portion of the ilium to the stress provoked by the compressive forces acting on it [32]. This angle is formed between a horizontal and a tangential line extending from the medial to lateral edges of the sourcil (Table 1 and Fig. 5). A weightbearing acetabular index equal to or less than 13° is considered normal [33], whereas a measurement greater than 13° is a radiographic sign of hip dysplasia. The interobserver reproducibility of the acetabular index radiographic measurement has been reported to be satisfactory on the basis of the ICC of 0.84 (95% CI, 0.73–0.90) and a kappa coefficient of 0.71 (95% CI, 0.47–0.93), indicating substantial reproducibility [29].

Fovea Alta Measurements

Nötzli et al. [34] reported the abnormal superior position of the fovea capitis, also referred to as “fovea alta,” in the adult dysplastic hip as a potential radiographic diagnostic marker. These authors quantified the position of the fovea capitis along the femoral head with the use of the delta angle measured on radiographs in the anteroposterior view. On MRI, a mid-coronal MR image in which the fovea capitis is seen best is selected using triangulation with the sagittal and coronal planes. The delta angle is formed between the lines drawn from the center of the femoral head to the medial edge of the sourcil and to the superior edge of the fovea capitis [34] (Table 1 and Fig. 6). A normal delta angle is greater than 10° and a dysplastic hip with fovea alta has a delta angle ≤ 10°. Nötzli et al. suggested that fovea alta might serve as a contributing factor in the development of coxarthrosis by decreasing the contact area of the femoral head with the superior weightbearing articular surface of the acetabulum, thus, predisposing to acetabular articular cartilage injury. Further research is needed to determine the role of the fovea alta as a diagnostic marker of hip dysplasia and its potential association with pathology in the hip joint.

Cross-Sectional Imaging

CT

Several studies have assessed the utility of CT in the precise evaluation of acetabular morphologic deficiencies. CT is useful for
characterizing adult hip dysplasia to anterior, posterior, or global deficiency [35–41]. In addition, the modality can be used to measure and confirm the 2D CT correlates of radiographic center-edge angle, vertical-center-anterior margin, and acetabular index.

Axial CT images can also provide morphologic analysis of acetabular deficiencies by measuring the anterior acetabular sector angle, the posterior acetabular sector angle, and the horizontal acetabular sector angle [37] (Table 2 and Fig. 7). The measurements are obtained using the axial CT slice located one cut above the greater trochanters. The anterior acetabular sector angle assesses for adequate anterior coverage of the femoral head by the acetabulum and is measured by drawing lines through the center of the femoral head and the contralateral femoral head and tangent to the anterior lip of the acetabulum. Adequate anterior acetabular coverage is present when the anterior acetabular sector angle is greater than 50°. The posterior acetabular sector angle evaluates for adequate posterior coverage of the femoral head by the acetabulum and is measured by drawing lines through the center of the femoral head and the contralateral femoral head and tangent to the posterior lip of the acetabulum. Adequate posterior acetabular coverage is present when the posterior acetabular sector angle is greater than 90°. The horizontal acetabular sector angle evaluates for global deficiency of femoral head coverage by the acetabulum and is measured by drawing lines from the anterior lip of the acetabulum through the center of the femoral head and posterior lip of the acetabulum and the posterior lip of the acetabulum. Adequate global acetabular coverage is present when the horizontal acetabular sector angle is greater than 140° [35]. These measurements have been described only with CT. To the best of our knowledge, there are no published data available to support the use of MRI for calculating these measurements.

The 3D reconstruction capabilities of CT have enabled a more precise evaluation of the severity of acetabular dysplasia [21, 37, 39, 42, 43]. CT can contribute to the radiographic assessment of hip dysplasia in the preoperative evaluation of the type and degree of acetabular deficiency [21]. Three-dimensional CT is useful because it provides the surgeon with a preoperative road map for correction of the acetabular deficiency, which may not be

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<tr>
<td>Anterior acetabular sector angle</td>
<td>Axial CT one cut above greater trochanter</td>
<td>Angle between lines through centers of both femoral heads and line tangent to anterior lip of acetabulum</td>
<td>Normal &gt; 50° Dysplastic ≤ 50°</td>
<td>7</td>
</tr>
<tr>
<td>Posterior acetabular sector angle</td>
<td>Axial CT one cut above greater trochanter</td>
<td>Angle between lines through centers of both femoral heads and line tangent to posterior lip of acetabulum</td>
<td>Normal &gt; 90° Dysplastic ≤ 90°</td>
<td>7</td>
</tr>
<tr>
<td>Horizontal acetabular sector angle</td>
<td>Axial CT one cut above greater trochanter</td>
<td>Angle between lines from anterior lip of acetabulum through center of femoral head and posterior lip of acetabulum</td>
<td>Normal &gt; 140° Dysplastic ≤ 140°</td>
<td>7</td>
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Fig. 7—Measurement of anterior acetabular sector angle (AASA), posterior acetabular sector angle (PASA), and horizontal acetabular sector angle (HASA).

A, Drawing shows measurement of anterior acetabular sector angle (AASA), posterior acetabular sector angle (PASA), and horizontal acetabular sector angle (HASA). Values are measured on axial CT one cut above greater trochanters. Anterior acetabular sector angle is created by drawing lines through centers of femoral heads and line tangent to anterior lip of acetabulum. Adequate anterior acetabular coverage is present when anterior acetabular sector angle is greater than 50°. PASA is measured by drawing lines through centers of femoral heads and line tangent to posterior lip of acetabulum. Adequate posterior acetabular coverage is present when PASA is greater than 90°. HASA is measured by drawing lines from anterior lip of acetabulum through center of femoral head and posterior lip of acetabulum. Adequate global acetabular coverage is present when HASA is greater than 140°.

B, CT image in 29-year-old woman shows dysplastic hip with deficient anterior coverage (anterior acetabular sector angle < 50°), deficient global coverage (HASA < 140°), and borderline deficient posterior coverage (normal PASA > 90°).
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CT-based assessment of hip dysplasia has the disadvantages of radiation exposure of the patient and relative insensitivity to early changes of cartilage damage. Conversely, CT arthrography, with direct intraarticular injection of contrast material, has been shown to be a sensitive and reproducible method for assessing substantial articular cartilage loss in patients with hip dysplasia [44]. Limitations of the latter technique, however, include invasiveness, higher cost, and relative inaccessibility.

MRI

Several studies have evaluated the utility of MRI in the evaluation of hip dysplasia [22, 44–49]. The lack of ionizing radiation exposure is an obvious advantage of MRI over radiography and CT. Similar to the latter techniques, MRI provides morphologic information about acetabular deficiency in hip dysplasia. Chen et al. [22] showed that MRI measurements of center-edge angle using anterior to middle coronal MR images determined by triangulation with sagittal and axial images in which the femoral head forms a circle correlate well with radiographic measurements and can be used to assess acetabular deficiency (Table 3 and Fig. 9). Conversely, center-edge angle measurements performed on posterior coronal slices, determined by triangulation with sagittal and axial images, correlated poorly with radiographic measurements [22].

Early detection of osteoarthritis [44, 45], manifested as chondral and labral damage, can also be assessed using MRI. Nishii et al. [49] reported chondral defects along the acetabular articular cartilage in dysplastic hips. Reported MRI findings of labral disease in hip dysplasia include morphologic alterations, such as labral hypertrophy and tear (Fig. 10); labral intrasubstance signal change; and labral chondral junction disruption [45]. Ligamentum teres elongation, degeneration, and tear can also be visualized. Detection of all these abnormalities can be improved with direct MR arthrography. With indirect MR arthrography, however, there have been conflicting reports regarding effectiveness in detecting articular cartilage lesions in the hip. A study by Pozzi et al. [50] showed that in a series of 21 hip joints, indirect MR arthrography showed higher sensitivity (92%) and accuracy (95%) than standard MRI in detecting chondral damage. In contrast, Zlatkin et al. [51] showed that in a series of 14 hip joints, identification of chondral abnormalities was not improved using indirect MR arthrography over conventional MRI.

A few studies have evaluated the effectiveness of applying leg traction during MRI of the hip to differentiate between acetabular and femoral cartilage by interposition of a joint fluid layer, and these studies have shown improved detection of cartilage lesions on traction images compared with nontraction images [52–54]. This technique may be a further step toward better imaging of cartilage defects of the hip that warrants further investigation; however, it has not yet become a part of routine clinical practice. Advanced biochemical MRI techniques, such as delayed gadolinium-enhanced MRI of cartilage (dGEMRIC), T2 mapping, and T1-rho

TABLE 3: MRI Measurements of Developmental Dysplasia of the Hip

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<tr>
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<th>Technique</th>
<th>Description</th>
<th>Normal vs Abnormal Values</th>
<th>Example Figure</th>
</tr>
</thead>
</table>
| Center-edge angle | Anterior to mid-coronal | Angle between vertical line through femoral head center and line tangential to lateral margin of acetabulum | Normal > 25°  
Borderline dysplasia = 20–25°  
Dysplasia < 20° | 9 |
| Delta angle | Mid-coronal | Angle between lines drawn through medial edge of sourcil and superior edge of fovea capitis through femoral head center | Normal > 10°  
Fovea alta ≤ 10° | 6 |

Fig. 8—Normal and dysplastic hips. A and B, Three-dimensional volumetric reformatted images show 48-year-old man (A) without hip dysplasia (diagnostic-quality images not shown) with normal position of fovea capitis (circle) and 37-year-old woman (B) with hip dysplasia (diagnostic-quality images not shown) with high position of fovea capitis (circle) or "fovea alta."
can detect biochemical changes of the articular cartilage in the hip joint and therefore have the potential to detect chondral injury in dysplastic hips early in the disease process before radiographically noticeable coxarthrosis. The position of the fovea capitis can easily be determined with the delta angle measurement on MRI (Table 3)[55].

**Differentiating Hip Dysplasia From Femoroacetabular Impingement**

Repetitive microtrauma from impingement of the femoral head against the acetabulum is believed to be the likely cause in femoroacetabular impingement. There are two potential morphologic abnormalities that may occur in isolation or concurrently: pincer deformity referring to overcoverage of the femoral head by the acetabulum and cam deformity representing loss of femoral head and neck offset. Associated injuries, best seen on MRI related to the impingement include contrecoup posterior-inferior chondrolabral injury (pincer type) and anterior femoral head and neck edema or cystic changes (cam type). In contrast to hip dysplasia, the primary abnormality in pincer-type femoroacetabular impingement is overcoverage of the femoral head, such as seen in cases of coxa profunda. Similarly, with cam-type

![Fig. 9—MRI measurement of center-edge angle. A and B, Coronal T1-weighted images of pelvis show measurement of center-edge angle as it is applied to MRI in 27-year-old woman (A) with normal center-edge angle > 25° and 32-year-old woman (B) with dysplastic hip with center-edge angle < 20°.](image)

![Fig. 10—32-year-old woman with hip dysplasia and labral disease. A–C, Coronal proton density-weighted (A) and sagittal fat-saturated proton density-weighted (B and C) MR images show redundant patulous labrum with extensive intrasubstance signal abnormality (curved arrows, A and B) associated with anterior acetabular subchondral cysts (dashed arrow, C). D, Anteroposterior pelvis radiograph performed 7 days before MRI shows center-edge angle of 12° in right hip, which is consistent with developmental dysplasia of hip. Although femoral head undercoverage appears subtle, particularly on MRI study, this patient has significant undercoverage of right femoral head based on center-edge angle, which can easily go undetected.](image)
femoroacetabular impingement, the primary abnormality is the decreased femoral head and neck offset rather than undercoverage of the femoral head seen in hip dysplasia. Nevertheless, there is often difficulty in differentiating collar-type osteophytes secondary to secondary osteoarthritis in mild hip dysplasia versus a femoral head and neck osseous bump. A normal center-edge angle noted in isolated cam morphology is in contradistinction to the typically decreased center-edge angle in hip dysplasia.

Complications of Hip Dysplasia

Subchondral Fractures

Most cases of subchondral insufficiency fractures occur in the absence of significant trauma, suggesting an underlying subchondral bone insufficiency, such as osteoporosis or excessive mechanical stress on the subchondral bone, such as occurs in hip dysplasia [56, 57]. A study by Obermayer-Pietsch et al. [58] evaluated 240 premenopausal women (age 33 ± 7 years) using dual-energy x-ray absorptiometry and biochemical parameters of bone metabolism and showed a 6.3-fold increased risk for low bone mineral density at the hip but not in the lumbar spine in patients with developmental hip dysplasia. The authors concluded that a history of conservatively treated developmental hip dysplasia may be a major risk factor for low bone mineral density at the hip in about one in 10 women. Deficient lateral acetabular coverage of the femoral head, characteristic of hip dysplasia, may result in diffuse chondral injury along the acetabular and femoral head articular surfaces. Secondary subchondral bone impaction fracture of

Fig. 11—28-year-old woman with left hip dysplasia and subchondral impaction fracture. A, Coronal fat-saturated T2-weighted MR image of pelvis shows deficient acetabular roof in left hip (center-edge angle < 20°), consistent with hip dysplasia. B and C, Coronal proton density–weighted (B) and coronal fat-saturated T2-weighted (C) MR images show subchondral fracture line (arrow) located in superior weightbearing aspect of femoral head. Note subtle subchondral plate indentation, minimal cortical flattening, and surrounding bone marrow edema.

Fig. 12—Hip dysplasia. A–C, Anteroposterior pelvis radiographs cropped to involved hip in 43-year-old woman (A) with right hip dysplasia shown by deficient lateral femoral head coverage (white arrow) and changes of mild secondary osteoarthritis, including mild superior joint space narrowing and osteophyte formation (black arrows); 37-year-old woman (B) with left hip dysplasia shown by deficient lateral femoral head coverage (white arrow) and changes of moderate secondary osteoarthritis, including moderate superior joint space narrowing and marginal osteophyte formation (black arrows); and 40-year-old man (C) with right hip dysplasia shown by deficient lateral femoral head coverage (white arrow) and changes of severe secondary osteoarthritis, including bone-on-bone superior joint space narrowing and large marginal osteophyte formation (black arrows).
the superior femoral head, where there is maximum force during weightbearing, can ensue. Motomura et al. [57] reported subchondral insufficiency fracture of both the acetabulum and femoral head in a patient with developmental hip dysplasia. Ishihara et al. [59] noted a greater incidence of hip dysplasia in patients with subchondral insufficiency fractures of the femoral head compared with asymptomatic hips, speculating that the fractures are due to excessive stress on the acetabular edge in the dysplastic hips. Subchondral insufficiency fracture is easily detected on MRI as a subchondral fracture line or flattening of the subchondral plate, subchondral collapse, and extensive subchondral bone marrow edema (Fig. 11).

Osteoarthritis

Early coxarthrosis is a major complication of delayed diagnosis and treatment of hip dysplasia in the young adult. Osteoarthritis is expected to ensue in all hips with untreated moderate hip dysplasia (a lateral center-edge angle of 15°) by the seventh decade of life [2]. In addition to providing assessment of lateral femoral head undercoverage, characteristics of hip dysplasia, radiography and cross-sectional imaging also show superior joint space narrowing with bone-on-bone contact, osteophyte formation, subchondral sclerosis, and cystic change, all imaging markers of osteoarthritis (Fig. 12).

Currently, the diagnosis of osteoarthritis is based on radiographic findings, which are a late manifestation of the disease process. MRI has the potential to detect chondral injury in dysplastic hips, early in the disease process before radiographically noticeable coxarthrosis. Kim et al. [46], using dGEMRIC, showed a direct correlation for the delayed gadolinium-enhanced MRI of the cartilage index—a measure of the biochemical integrity of cartilage—and the pain and grade of dysplasia. The dGEMRIC index was significantly different among groups of hips with mild, moderate, and severe dysplasia, suggesting that it may be a sensitive measure of early osteoarthritis. Jessel et al. [60] subsequently also identified patient age, severity of the dysplasia, and the presence of a labral tear as factors associated with clinically relevant osteoarthritis based on the dGEMRIC index. Treatment response in patients with hip dysplasia after periacetabular osteotomy can also be measured using MRI by assessment of the articular cartilage thickness. Mechenburg et al. [61] showed no significant changes in cartilage thickness manifested by stable chondral thinning in MRI follow-up 2.5 years after surgery compared with baseline preoperative MRI as a short-term outcome indicator after periacetabular osteotomy. These emerging advanced MRI techniques have great potential in predicting disease progression in hip dysplasia and showing response to therapeutic interventions. However, their precise role in routine clinical practice has yet to be determined.

Conclusion

Delayed diagnosis of mild hip dysplasia is an important cause of secondary osteoarthritis despite routine screening of infants, accounting for approximately 25% of all patients requiring total hip arthroplasty. The radiographic diagnosis of hip dysplasia in the young adult may be subtle. CT and MRI provide additional morphologic information about acetabular deficiency in hip dysplasia. MRI can also detect associated intraarticular injuries to the articular cartilage, labrum, and the ligamentum teres. Familiarity with the radiographic and cross-sectional imaging findings of mild dysplasia may allow timely implementation of appropriate treatment strategies to prevent the development of early osteoarthritis of the hip in the young adult population.

References

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