

# Developmental Dysplasia of the Hip in Adolescents and Young Adults

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## Abstract

Developmental dysplasia of the hip (DDH) in adolescents and young adults can cause notable pain and dysfunction and is a leading cause of progressive hip osteoarthritis in affected patients. Recognition of the clinical symptoms and radiographic presentation of DDH in adolescents and young adults are paramount for early management. Plain radiographs are critical for making proper diagnosis, whereas three-dimensional imaging including MRI and/or CT detects intra-articular pathology and better characterizes hip morphology. Management of early, symptomatic DDH includes nonsurgical modalities and open joint preservation techniques. Arthroscopic management can be used as an adjunct for symptomatic treatment and for addressing intra-articular pathology, but it alone does not correct the underlying osseous dysplasia and associated instability. The periacetabular osteotomy has become the mainstay of efforts to redirect the acetabulum and preserve the articular integrity of the hip; however, the proximal femur is also a potential source of pathology that should be considered. Open hip procedures are technically demanding yet provide the opportunity for pain relief, improved function, and preservation of the hip joint.

Developmental dysplasia of the hip (DDH) represents a spectrum of pathology involving the acetabulum and occasionally the proximal femur with implications over a lifetime.<sup>1-5</sup> The transition in terminology from “congenital hip dislocation” to “developmental dysplasia of the hip” reflects an evolution in the understanding of the symbiotic development of the femoroacetabular joint. During infancy, the plasticity of the hip allows for a variety of nonsurgical treatment modalities to reposition the femoral head as a template for acetabular development. Throughout childhood, osteotomies of the pelvis and proximal femur have been developed

to encourage normal morphology at skeletal maturity; however, many cases of dysplasia remain unrecognized, or residual dysplastic features persist despite treatment and present to the clinician after triradiate cartilage closure.<sup>6</sup> The contemporary concept of symptomatic adolescent and adult hip dysplasia includes the potential for pathologic instability of the hip joint. This hip instability includes abnormal movement of the femoral head within the acetabulum because of both osseous and soft-tissue abnormalities that lead to overload of the acetabular rim complex and heightened risk of chondral degeneration and secondary osteoarthritis (OA).<sup>7</sup> The variability in

pattern of acetabular bony deficiency and proximal femoral morphologies, including femoral anterversion, coxa valga, head-neck junction deformities, and head asphericity, are increasingly recognized as important factors in the diagnosis and management of the dysplastic hip. The treating physician must be aware of the presenting symptoms and imaging findings in this patient cohort to ensure appropriate workup and accurate diagnosis to guide treatment and optimize patient outcomes.

### Epidemiology and Natural History

Hip pain is common among active adolescents and young adults, and DDH represents one of many potential etiologies.<sup>8,9</sup> The true prevalence of DDH remains unclear, as it is often asymptomatic, and discrepancies exist in the radiographic definition used between studies. A cross-sectional, cohort-based study of 3,620 Danish adults found a prevalence of 4.3% in men and 3.6% in women.<sup>10</sup> A cross-sectional survey of 25,767 Chinese adults found an overall prevalence of 1.52%, with 2.07% in women and 0.75% in men.<sup>11</sup> Interestingly, when looking at demographics of patients presenting for treatment, the numbers are quite different. In one cohort study of 950 patients treated with periacetabular osteotomy (PAO), 83% were women, 87.2% were Caucasian, and 26.5% reported a family history of hip disease.<sup>12</sup> Lee et al<sup>13</sup> noted similar findings in a cohort of 421 patients treated with PAO at a single, large referral center. Known risk factors for DDH include breech presentation, female sex, primiparity, and family history. For many years, severe untreated DDH has been accepted as a risk factor for the

development of early-onset OA; however, since the late 1980s, investigations have demonstrated that less severe acetabular deformities also contribute to early joint degeneration.<sup>3,14-16</sup> In a cohort of 710 hips treated with total hip arthroplasty (THA) in patients aged 50 years or younger, Clohisy et al<sup>17</sup> found that DDH and femoroacetabular impingement (FAI) (48.4% and 35.9%, respectively) accounted for most hips with premature OA, whereas 9.5% had evidence of Legg-Calvé-Perthes and 6.2% with slipped capital femoral epiphysis. A similar study by Wyles et al<sup>18</sup> reviewed the contralateral hip in 722 patients who underwent THA from 1980 to 1989 and found that DDH had the greatest increased risk of progression from Tönnis 0 to Tönnis 3 or implantation of THA compared with patients with normal hip morphology (hazard ratio 5.0).

### Presenting Symptoms

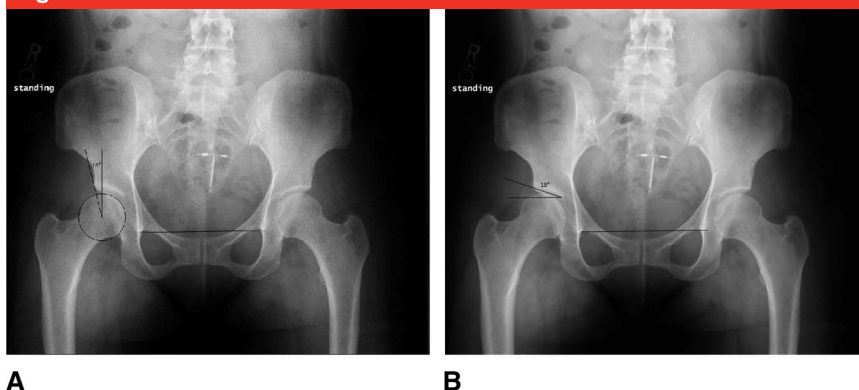
The evaluation of hip pain in the young adult patient should begin with a detailed interview, ideally including an intake questionnaire, to help narrow down the location, character, and duration of symptoms. In addition, an effort should be made to define a potential pattern of symptoms. Careful attention must be paid to inciting activities or positions, activity level, and previous treatments.<sup>8</sup> The most common feature in the presentation of symptomatic hip dysplasia is groin pain of insidious onset.<sup>19</sup> As with other intra-articular sources of pain about the hip, this is frequently demonstrated with the indication of pain in a c-shaped distribution about the inguinal crease.<sup>8</sup> Lateral-based pain and a limp or Trendelenburg gait are also seen with abductor fatigue and typically

worsen with prolonged activity.<sup>19</sup> A remote history of minor trauma or overexertion is not uncommon. Frequent exacerbating activities include those that cause hip flexion or external rotation in weight-bearing stance and prolonged time in a single position (sitting or standing). Symptoms consistent with iliopsoas irritability can also alert the treating physician to potential hip dysplasia or instability.<sup>20</sup> Although most patients are active and otherwise healthy, common comorbid conditions include back pain and depression.<sup>12</sup> In many cases, the presenting symptoms of DDH in this cohort may be very similar to those of other common conditions such as FAI. One should also be careful not to overlook the initial presentation of an inflammatory arthropathy in this age group. Activity level and severity of dysplasia have also been implicated in the age at symptom onset and the likelihood of progression to treatment. Matheney et al<sup>21</sup> showed in a review of 708 hips treated with PAO that a high activity level, as defined by the UCLA score, and more severe radiographic dysplasia led to the development of symptoms at an early age. These effects were found to be synergistic, as the average age at PAO in highly active patients with severe dysplasia was found to be notably younger than the average age at PAO in minimally or moderately active patients with mild or moderate dysplasia (21 versus 28 years, respectively).

### Physical Examination

The physical examination should include an evaluation of gait, abductor strength, range of motion, and impingement maneuvers. Frequent findings include abductor fatigue

seen with a Trendelenburg sign, pain with impingement testing (flexion, adduction, and internal rotation), and a normal or increased range of motion.<sup>12,19</sup> Such aberrations in the arc of motion may arise from alterations in femoral torsion or hyperlaxity of the surrounding soft tissues, and identifying the source will have profound implications on the ultimate management plan. Sankar et al<sup>22</sup> showed in a study of 314 patients treated with PAO that femoral torsion was correlated with clinical range of motion. With the hip examined in flexion, they found that increased femoral version was associated with increased hip internal rotation and decreased hip external rotation. Concern for generalized ligamentous or capsuloligamentous laxity should be evaluated and documented using the Beighton<sup>23</sup> criteria. Specific tests may also be useful to assess instability in the prearthritic hip and consist of a series of maneuvers intended to load the anterior labrum and capsule in an effort to replicate the patient's symptoms. The anterior apprehension sign of the hip places the femoral head in an unstable position, causing anterior subluxation with associated discomfort or apprehension. The anterior apprehension sign is performed in the lateral decubitus or prone position, by placing the hip in extension. As the examiner applies progressive external rotation and adduction to the examined leg, one looks for apprehension or pain.<sup>24</sup> A prone external rotation test with an anterior-directed force on the posterior greater trochanter that reproduces pain can also signify anterior instability.<sup>25</sup> A log roll test, demonstrating capsular laxity of the hip, is performed supine and is positive when the affected leg has more external rotation than the contralateral leg in a resting position.<sup>24</sup> Also, the dial test can be performed where the femur and tibia are maxi-

**Figure 1**

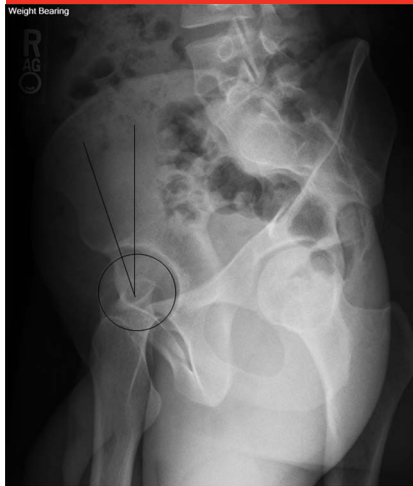
**A**, AP radiograph showing the LCEA that is formed between a line vertical from the center of the femoral head and a line to the lateral aspect of the weight-bearing acetabulum. An LCEA  $<20^\circ$  represents dysplasia,  $20^\circ$  to  $25^\circ$  is consistent with borderline dysplasia, and  $25^\circ$  to  $39^\circ$  represents the normal range. **B**, AP radiograph showing the Tönnis angle between horizontal and a line measuring the slope of the sourcil. Values greater than  $>10^\circ$  are consistent with acetabular dysplasia. LCEA = lateral center-edge angle

mally internally rotated, released, and allowed to return to external rotation. A test is considered positive if the leg releases past  $45^\circ$  of external rotation from vertical.<sup>26</sup> However, instability is a multifactorial diagnosis, and these tests collectively remain poorly sensitive or specific and are often negative in the setting of mild or moderate acetabular dysplasia.

### Radiographic/Imaging Workup

The radiographic evaluation of the young adult hip consists of the standing AP pelvic view and a false-profile view and a lateral view of the proximal femur (commonly a  $45^\circ$  Dunn view and/or frog-leg view).<sup>27</sup> On the AP pelvic view, the lateral center-edge angle (LCEA) of Wiberg can be used to assess superolateral coverage of the femoral head by the acetabulum. Patients with LCEA  $25^\circ$  to  $39^\circ$  are considered normal, measurements of  $<20^\circ$  are considered dysplastic (Figure 1A), and those  $20^\circ$  to  $25^\circ$  are considered “borderline”.<sup>27</sup> On the AP pelvic view, the inclination of the weight-

bearing surface of the acetabulum, or sourcil, is measured with the Tönnis angle (Figure 1B). A diagnosis of dysplasia is consistent with values  $>10^\circ$ .<sup>27</sup> From the false-profile view, the anterior center-edge angle, or angle of Lequesne, can be measured (Figure 2). This measurement assesses the anterior coverage of the femoral head, and values  $25^\circ$  to  $40^\circ$  are considered normal, values  $<20^\circ$  are indicative of dysplasia, and values  $>40^\circ$  can be associated with FAI.<sup>8,27</sup> Owing to the reliance of these classic measurements on the superimposition of osseous structures, a critical evaluation must be made of the technical adequacy of the images and should include an assessment of the pelvic rotation and tilt before conclusions are drawn.<sup>28,29</sup> Despite these limitations, the intraclass correlation coefficient values for the LCEA, anterior center-edge angle, and Tönnis angle have overall been shown to be strong in a systematic review of 43 studies conducted over the past 15 years.<sup>29</sup> However, concerns with interobserver reliability arise when the study group includes more than

**Figure 2**

ACEA is measured on a weight-bearing false-profile radiograph. It is the angle formed between a line vertical from the center of the femoral head and a line to the anterior sclerotic rim of the weight-bearing portion of the acetabulum. Values  $< 20^\circ$  represent dysplasia,  $20^\circ$  to  $39^\circ$  represents the normal range, and  $\geq 40^\circ$  is consistent with pincer-type femoroacetabular impingement. ACEA = anterior center-edge angle

two reviewers.<sup>30,31</sup> In an effort to further improve reliability, the software has been designed to offer computer-assisted measurements with promising results.<sup>30</sup> The same cannot be said for other radiographic findings to include the Tönnis grade of OA, which demonstrates notable variability among observers even when computer assistance is incorporated.<sup>29,30</sup>

Owing to the inherent limitations of static, two-dimensional measurements and the ambiguous terminology of “borderline” dysplasia, additional radiographic indices have been developed in an effort to predict stability and better define coverage deficiencies. The Femoro-Epiphyseal Acetabular Roof index represents the angle formed between the horizontal portion of the central proximal femoral physeal scar and the acetabular index (Figure 3). In a

**Figure 3**

AP radiograph showing the FEAR index that represents the angle formed between the horizontal portion of the central proximal femoral physeal scar and the acetabular index. Values less than  $5^\circ$  have been shown to help predict stability of the hip. FEAR = Femoro-Epiphyseal Acetabular Roof

case-control study of 39 symptomatic hips with LCEA  $< 25^\circ$  (21 deemed unstable and treated with PAO) and 20 asymptomatic control subjects with LCEA  $> 25^\circ$ , Wyatt et al<sup>32</sup> showed that a Femoro-Epiphyseal Acetabular Roof index lower than  $5^\circ$  had a 79% probability of correctly labeling the hip as stable and not requiring management. Another key parameter that has been somewhat overlooked is relative contributions of the anterior and posterior wall in the coverage deficiencies seen with dysplasia.<sup>33</sup> Wilkin et al<sup>34</sup> proposed that in addition to the LCEA, anterior and posterior wall indexes be measured, thereby eliminating the ambiguous term “borderline” dysplasia and replacing it by three broad groups of acetabular deficiency or instability: anterior, posterior, and lateral/global. In this system, patients with anterior instability experience symptoms with anterior apprehension testing, as described previously, and demonstrate a decreased anterior wall index, negative crossover sign, reduced anterior acetabular sector angle on CT, and a normal LCEA. Patients with posterior instability

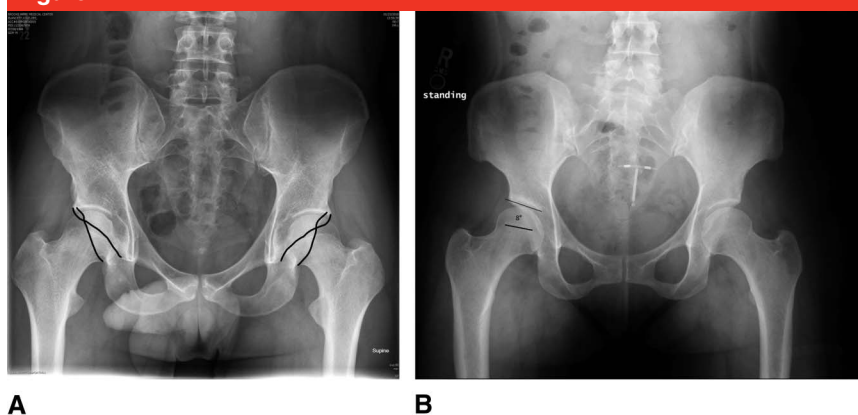
demonstrate acetabular retroversion with anterior overcoverage and may present with pain with activities that load the hip loaded in flexion, a history of piriformis syndrome refractory to management, vague sciatic nerve symptoms, or pain with impingement testing. Imaging in this form of instability reveals a crossover sign, an ischial spine sign, a decreased posterior wall index, a reduced posterior acetabular sector angle on CT, and a normal LCEA. The final group of instability, lateral/global, is most consistent with the understanding of dysplasia with superolateral acetabular deficiency and a reduced LCEA; however, these patients too may demonstrate relative anterior, posterior, or global deficiency as described by Nepple et al.<sup>35</sup>

One of the most difficult features to assess on plain radiographs of the pelvis is acetabular version. The crossover sign refers to the intersection of the lines formed by the anterior and posterior walls of the acetabulum seen below the lateral aspect of the sourcil on the AP pelvic radiograph (Figure 4). It is generally associated with acetabular retroversion; however, its specificity and utility have been questioned by more recent studies assessing acetabular version and coverage with CT.<sup>27,35-37</sup> Also, posterior wall sign indicating a posterior wall that passes medial to the center of the femoral head has been indicated in hips that are dysplastic, although it can be seen in normal control subjects as well.<sup>33</sup> Close attention should be paid to the tilt and rotation of the pelvis, as seemingly minor flaws in the imaging technique or patient posture can have notable effect on the assessment of version.<sup>38</sup>

In patients with radiographic and clinical evidence of DDH, the inclusion of three-dimensional (3D) imaging is important for preoperative



planning and adequate assessment of the deformity. Magnetic resonance (MR) imaging or MR arthrogram may function as an adjunct in the evaluation of adolescents and young adults with DDH. Findings may include hypertrophy and/or tearing of the labrum, capsular thickening, hypertrophy of the iliocapsularis, and various stages of cartilage injury.<sup>39-41</sup> Petchprapa et al<sup>42</sup> have shown that with musculoskeletal radiologists interpreting MR arthrogram on a 3-Tesla scanner, they were 98% sensitive and 99% specific with regard to labral pathology seen at the time of arthroscopy, whereas cartilage injury detection was 69% sensitive but 99% specific. To improve the preoperative assessment of articular cartilage, several imaging techniques have been developed that seek to identify early changes in the cartilage matrix structure or composition. T2 relaxation time, or T2 mapping, represents one such effort, which assesses the water and collagen content of the extracellular matrix and collagen fiber orientation to produce a map of cartilage matrix degeneration.<sup>43,44</sup> Sodium imaging is a technique that evaluates the fixed charge density of articular cartilage as an indication of glycosaminoglycan content.<sup>45</sup> Both of these techniques have the benefit of assessing qualitative markers of articular cartilage and do not require contrast administration; however, they have yet to be adequately studied in the preoperative assessment of patients with hip dysplasia. Glycosaminoglycan content can be evaluated with delayed gadolinium-enhanced magnetic resonance imaging of cartilage, which has been used in an attempt to detect early arthritic changes and, thus, identify patients who are poor candidates for

**Figure 4**

**A**, AP radiograph showing the crossover sign that represents focal acetabular retroversion, as the anterior wall projects more lateral to the posterior wall at the superior aspect of the acetabulum and “crosses over” the projection of the posterior wall further caudally. **B**, Shows evidence of bilateral cam lesions along with global retroversion of the acetabulum with deficient posterior coverage.

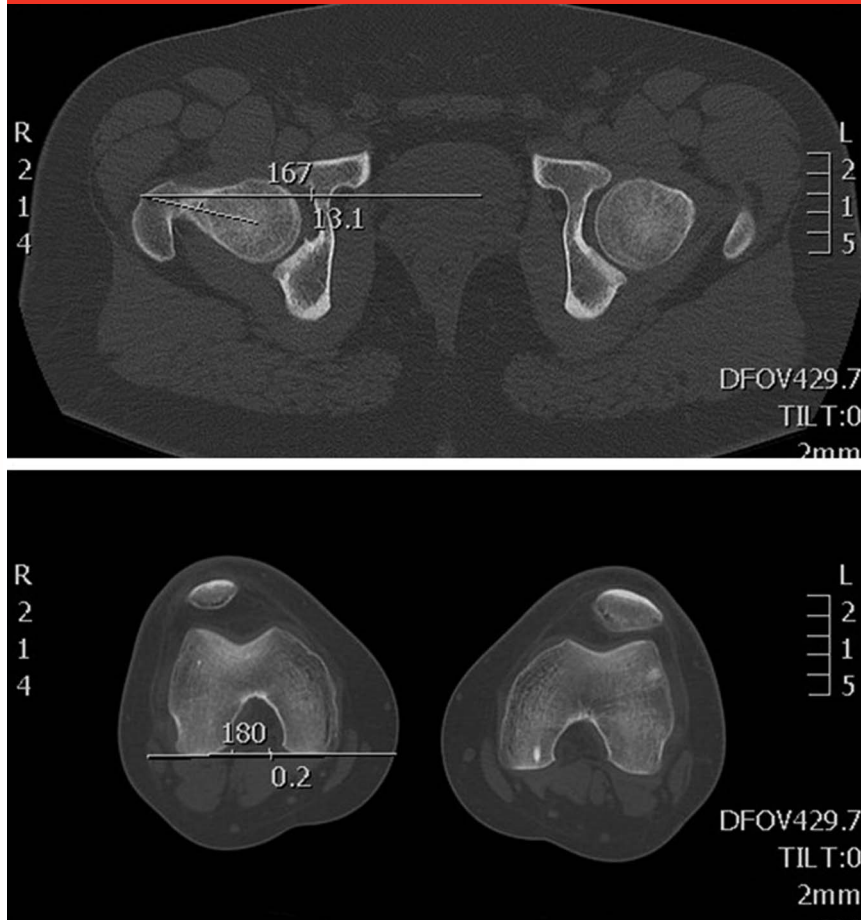
reconstructive pelvic osteotomy.<sup>46</sup> However, recent studies have shown permanent deposition of gadolinium in the brain tissues including the dentate nucleus and globus pallidus, even in patients without renal dysfunction.<sup>47</sup> Although little is known regarding the long-term effect of these deposits, such finding raises concern regarding the utility of this imaging modality and may merit assessment with other noncontrast imaging techniques.

CT is also used for the objective assessment of both acetabular and proximal femoral osseous morphology including excessive anteversion or retroversion.<sup>5,35</sup> In patients with clinical evidence of excessive femoral anteversion, the distal femur should be included for accurate torsional assessment (Figure 5). The advent of 3D reformatting has also provided a helpful adjunct for conceptualizing and further subtyping acetabular deficiency along with helping define cam lesions in cases of dysplasia with femoral-sided FAI as well; however, direct translation of these measurements to two-dimensional intraoperative fluoroscopy or radiographs remains challenging.<sup>35</sup>

Although CT is a powerful tool for the assessment of DDH, one must not overlook the lifetime risks that frequent doses of ionizing radiation impart on these young patients. Advances in low-dose CT imaging now allow for studies with radiation doses on the order of three to five AP pelvis radiographs (0.75 to 1.25 mSv) or a 90% reduction compared with standard CT.<sup>35</sup> CT should not be relied on as a diagnostic tool by the primary care provider or surgeon who is not prepared to perform the definitive hip preservation procedure, which may lead to redundant or inadequate image sequencing in a cohort of patients who have often required advanced imaging as children or may require additional imaging in the future.

## Management Options

The management of symptomatic dysplasia in the adult should be predicated based on the patient's age, symptoms, activity demands, and integrity of the articular cartilage damage. Consideration should be given to the contributions of both acetabular and proximal femoral

**Figure 5**

Low-dose CT torsional profile with axial cuts at the hip and knee: With the femoral condyles, horizontal normal femoral version approximates 15° of anteversion. This patient demonstrates 13° of femoral retroversion or nearly 28° from normal values.

morphology and to the potential effect of present interventions on future reconstructive procedures. Current treatment for young patients without evidence of OA focuses on reconstructive pelvic osteotomies to improve congruence and position of the weight-bearing surface area of the acetabulum with limited roles for arthroscopy and nonsurgical regimen. The principles of treatment include achieving mechanical stability without causing secondary impingement.

### Nonsurgical Management

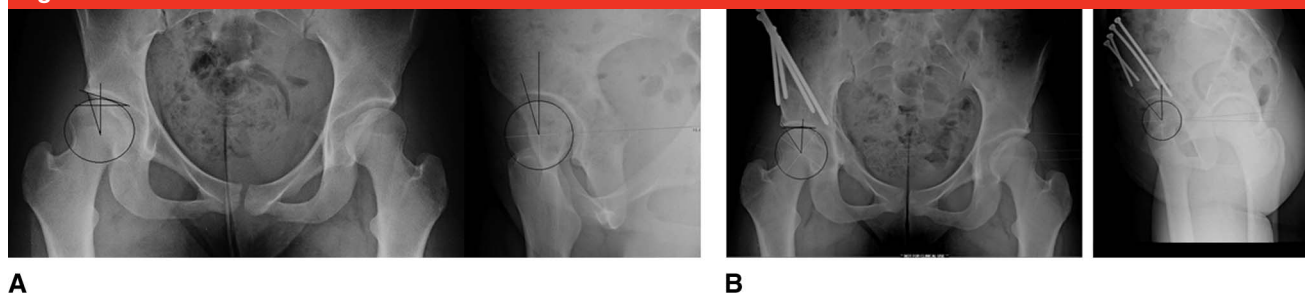
The role of long-term nonsurgical management in the setting of

symptomatic acetabular dysplasia is limited by the current understanding of its natural history with premature progression to end-stage arthritis and arthroplasty.<sup>14,15,17,18</sup> In patients with mild symptoms, mild deformity, contraindications, or those not amenable to reconstructive procedures, a trial of activity modification, NSAIDs, physical therapy, and intra-articular corticosteroid injections may offer symptom relief. Hip abductor strengthening, core strengthening, and avoidance of hip flexion type activities can help limit current symptomatology, but long-term benefits have yet to be elucidated or studied. Prolonged

nonsurgical management should follow the Clinical Practice Guidelines for the Management of Osteoarthritis of the Hip as published by the American Academy of Orthopaedic Surgeons.<sup>48</sup>

### Arthroscopy

In the past three decades, arthroscopy of the hip has emerged as a less-invasive approach for management of certain intra- and periarticular pathologies. In the setting of acetabular dysplasia, increased articular contact stress and subluxation of the femoral head is known to result in chondral injuries and labral hypertrophy with associated tearing.<sup>39</sup> Sankar et al<sup>49</sup> demonstrated this in a subset of 703 patients undergoing PAO with a concomitant arthroscopy (n = 192) or anterior arthrotomy (n = 511) to perform and osteochondroplasty of the femoral head-neck junction or address labral pathology. They demonstrated that in the 553 hips where the labrum was visualized, 50% had evidence of labral hypertrophy, with a correlation between decreased lateral and anterior coverage with increased rates of hypertrophy. They also found that in 64.2% of the labrums visualized had evidence of tearing, the most common type being degenerative in nature. Although arthroscopic approaches have demonstrated promise in the management of certain types of FAI, arthroscopy in isolation for dysplasia causing hip instability should be approached with great caution, as the chondral and labral pathology in DDH is sequelae of the osseous instability and may recur or progress if the underlying pathomechanical issue is not corrected.<sup>50,51</sup> Furthermore, efforts to address pincer-type impingement morphology through arthroscopy without an appreciation for altered acetabular version can have devastating results with subsequent iatrogenic instability of the

**Figure 6**

**A**, Preoperative images of a 24-year-old woman with symptomatic hip dysplasia. The patient has a decreased LCEA and ACEA with an increased Tönnis angle. **B**, Postoperative images of the same person after right-sided PAO. Improvements are noted in the LCEA and ACEA along with decrease in the Tönnis angle. ACEA = anterior center-edge angle, LCEA = lateral center-edge angle, PAO = periacetabular osteotomy

hip.<sup>52</sup> Currently, the ideal role of arthroscopy seems to be as an adjunct procedure to PAO in certain selected cases, as it allows enhanced visualization for management of chondral, labral, and proximal femoral cam-type pathology. Identification of notable arthritis in the weight-bearing portion of the acetabulum during arthroscopy can also identify patients who are not candidates for subsequent PAO. In addition, hip arthroscopy does not appear to have deleterious effects on bony correction performed in the same setting. Ricciardi et al<sup>53</sup> have shown that patients undergoing combination of hip arthroscopy to address intra-articular pathology in combination with PAO did not affect PAO surgical time or radiographic correction achieved in addition to showing similar improvements in PROs.

Management of borderline dysplasia (LCEA 20° to 25°) is more controversial because some patients may have symptomatic instability, whereas others have symptomatic impingement. Several natural history studies support the elevated risk of OA in this cohort, even extending as high as LCEA of 28°. <sup>54,55</sup> Evaluation of this cohort requires assessment of a variety of patient characteristics, physical examination findings, and radiographic features. Although

favorable short-term outcomes have been reported with either PAO or hip arthroscopy including labral repair and capsular plication,<sup>25</sup> the literature is lacking any direct comparisons of these approaches or mid- or long-term results. In addition, the published literature in the setting of borderline dysplasia generally has failed to comprehensively report important clinical factors in addition to the LCEA, including acetabular inclination, anterior center-edge angle, maximal alpha angle, and internal rotation in 90° of flexion. Future comparative research is needed to establish the optimal management strategy in the setting of borderline dysplasia.

### Pelvic Osteotomy

In patients with closed triradiate cartilage, the Le Coeur, Sutherland, Hopf, Steel, Tönnis, and Dial osteotomies have all been attempted in the past but had notable limitations that restricted their use.<sup>56</sup> In 1983, Ganz et al<sup>56</sup> developed a novel technique for PAO that preserved the integrity of the posterior column, allowed for large multidirectional corrections, maintained the shape of the true pelvis, preserved the acetabular blood supply, and could be performed through a single incision (Figure 6). In subsequent years, the

Bernese PAO has become the primary acetabular realignment osteotomy used for the management of dysplasia in skeletally mature patients because of its ability to address multiplanar deformities and permit less restrictive postoperative weight-bearing precautions. Subsequent analysis has demonstrated a reliable capacity to improve radiographic parameters and symptomatology, and evaluation with the delayed gadolinium-enhanced magnetic resonance imaging of cartilage index has revealed reductions in the mechanical loading of the articular cartilage through 2-year follow-up.<sup>57</sup>

From the initial 63 patients (75 hips) treated in the 1980s, Lerch et al<sup>58</sup> reported survivorship of 88% at 10 years, 61% at 20 years, and 29% at 30 years with defined end points of conversion to arthroplasty, progression of OA, and Merle d'Aubigné-Postel score <15.<sup>58</sup> In this cohort, risk factors identified for unfavorable outcomes were preoperative OA Tönnis grade >1, age >40 years at surgery, preoperative Merle d'Aubigné-Postel score <15, preoperative Harris Hip Score (HHS) of <70, preoperative limp, preoperative positive anterior or posterior impingement test, and preoperative internal rotation <20°. More modern studies show survival rates of 92% at 15 years and 74% at



18 years in two different cohorts of patients, demonstrating the potential for prolonged preservation of the natural hip joint in carefully selected patients.<sup>59,60</sup>

Given the complexity of the procedure and its notable learning curve, reliable outcomes data had previously been limited to small series and single-center cohorts. With an early research emphasis on survivorship of PAO, this has been more recently expanded to include short- and medium-term end points with a new focus on patient-reported outcomes that assess pain, hip function, activity level, overall health, and quality of life.<sup>61</sup> In a largest prospective cohort to date, Clohisy et al<sup>61</sup> recently reported 93% patient satisfaction at 2.6 years after PAO with marked improvements in hip and lower extremity functional scores, quality of life, and radiographic parameters of dysplasia.

The most frequent complications seen after PAO are similar to those associated with other reconstructive procedures of the hip and include lateral femoral cutaneous nerve dysesthesias, heterotopic ossification, venous thromboembolic disease, infection, iatrogenic impingement, and wound issues.<sup>61,62</sup> The rate of major complications, defined as modified Dindo-Clavien grade III or IV, has been reported from several prospective multicenter studies at around 7% with revision surgeries reported for symptomatic heterotopic ossification, intra-articular screw migration, posterior column fracture with nonunion, acetabular implant migration after trauma, and deep infection.<sup>61,62</sup> Despite promising results after PAO, some patients will eventually progress to THA. Amanatullah et al<sup>63</sup> compared THA after PAO with primary THA in patients with DDH performed at two major referral centers and found no reported differences in complications, revisions, or HHSs.

## Proximal Femoral Osteotomy

Common morphologic variations of the proximal femur in DDH include a shorter than normal neck, a smaller and straighter canal, increased anteversion, and head asphericity.<sup>5</sup> In a review of 3D CT scans in 103 hips (100 patients) that underwent PAO, Wells et al<sup>5</sup> noted abnormal morphology of the head and neck in 86% and cam morphology in 42% with maximal head-neck deformity at the 2-o'clock position. Because secondary impingement after rotational correction of the acetabulum can occur in patients following PAO, intraoperative dynamic clinical assessment of passive hip motion is mandatory following provisional correction. A minimum of 90° flexion and 15° internal rotation is suggested as a guideline to reduce the risk of postoperative FAI.<sup>5</sup> In the presence of secondary impingement, open treatment of the femoral head-neck junction should be performed to address cam morphology or residual morphology after failed arthroscopy. In a multicenter series of 391 hips treated with PAO, 230 patients were treated with concomitant femoral head/neck osteochondroplasty (either open or arthroscopic), 13 with intertrochanteric osteotomy, 4 with femoral neck relative lengthening, 3 with trochanteric advancement, and 2 with proximal femoral osteotomy (PFO).<sup>61</sup>

The goals of adjunct PFO are to enhance congruity, improve clinical abduction moment, advance the trochanter distally, or relieve secondary impingement.<sup>64</sup> PFO typically is reserved for cases of severe acetabular dysplasia with persisting instability or suboptimal joint congruency after PAO.<sup>64,65</sup> In such cases, abduction views can be added to the normal radiographic evaluation to assess the etiology of joint space narrowing. Hips with antero-

lateral migration of the femoral head that demonstrate improved congruency on abduction imaging are likely to benefit from PAO in isolation, whereas those that require the addition of 10° to 15° of flexion and/or internal rotation may benefit from concomitant PFO.<sup>65</sup> In a single-center database review, Clohisy et al<sup>64</sup> reported 15% of all patients treated with PAO underwent concomitant PFO and found similar improvement in hip function despite lower preoperative HHS compared with patients treated with PAO in isolation. In addition, the role of torsional abnormalities (increased femoral anteversion or femoral retroversion) needs to be further studied to elucidate their potential roles in hip stability, extra-articular impingement, and pain in the setting of dysplasia.

## Summary

DDH in the skeletally mature patient is a complex condition. Treating physicians must be cognizant of the presenting complaints, the physical examination findings, and the radiographic characteristics that can be frequently missed on initial presentation. DDH in the young active patient has a known association with premature joint deterioration and early OA. The mainstay of surgical management of congruous prearthritic DDH in adolescents and young adults is the PAO, the goal of which is to improve symptoms and prognosis by stabilizing the hip and reducing pathological articular forces through reorientation of the dysplastic acetabulum. PAO is a complex procedure that requires excellent patient selection and skilled execution. With proper training and modern-day techniques, long-term survivability improvements in patient-reported outcomes have been demonstrated with management of



DDH in the skeletally mature patient. Adjunct procedures to address intra-articular pathology, including labral and chondral injuries, can be managed through hip arthroscopy, but extreme caution should be exercised when considering hip arthroscopy alone in the setting of hip dysplasia. In addition, the surgeon should consider addressing aberrations in proximal femoral morphology when correcting the acetabular implant of DDH.

## Appendix 1

The ANCHOR Study Group Members who contributed to this article:

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