Hip Dysplasia in the Skeletally Mature Patient

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Abstract
Abnormal hip development causes one-quarter to one-half of all hip disease. Dysplastic hips typically share characteristic anatomic abnormalities. The dysplastic acetabulum is typically shallow, lateralized, and antverted with insufficient coverage anteriorly, superiorly, and laterally. The dysplastic proximal femur has a small femoral head with excessive femoral neck anteverision and a short neck with an increased neck shaft angle. These characteristic changes result in intraarticular pathology leading to hip arthritis. A variety of treatment options exist based on the degree of dysplasia and the amount of concomitant hip arthritis. Treatment options include hip arthroscopy, acetabular or femoral osteotomies, hip arthrodesis, and total hip arthroplasty.

According to the Center for Disease Control, 25% of Americans will experience symptomatic hip arthritis during their lifetimes, and it has been estimated that 20% to 50% of disease burden is secondary to acetabular dysplasia. Hip dysplasia refers to an abnormality in development, such as in size, shape, or organization, of the femoral head, acetabulum, or both. These changes may lead to increased contact pressures on the joint and ultimately to hip arthrosis. However, before the development of frank degenerative changes, many patients become symptomatic secondary to abnormal hip biomechanics, hip instability, impingement, or labral and chondral pathologies. These processes arise from increased and abnormal forces across the joint with resultant shear forces causing pathologic changes. Changes classically appear at the anterolateral region of the acetabulum, the posterior region of the femoral head, or the femoral head and neck junction.

Eventually, the mechanical hip dysfunction from dysplasia leads to early hip degeneration and osteoarthritis. It has been suggested that there is a direct correlation between the onset of radiographically determined degenerative joint disease and the amount of acetabular dysplasia present. Neonatal hip instability has been associated with a 2.6 times increased risk for total hip replacement in young adulthood in comparison to stable hips. And, one quarter of hip replacements performed in patients aged 40 years or younger are due to underlying hip dysplasia.

Hip dysplasia may be a primary process caused by congenital or developmental abnormalities. It has been well established that there is some genetic component to hip dysplasia. A positive family history for developmental hip dysplasia may be found in 12% to 33% of patients who have DDH. One study reported a tenfold increase in the incidence of DDH among the parents of index patients and a sevenfold increase among siblings compared with the incidence in the general population. Another study found that over 50% of patients requiring periacetabular osteotomy for hip dysplasia had a family history of hip dysplasia, and over 40% were first degree relatives. In addition, a number of secondary causes of dysplasia exist, including neuromuscular diseases, slipped capital femoral epiphysis, Perthes disease, trauma, or epiphyseal dysplasias.

Normal Hip Development
The formation of the hip joint begins at the seventh week of gestation. The acetabulum and the femoral head develop from the same group of mesenchymal stem cells. The seventh week of gestation, a cleft develops in the precarti...
laginous cells. This cleft defines the acetabulum from the femoral head. By the 11th week of gestation, the hip joint is fully formed, but acetabular development continues throughout intrauterine life, particularly by means of growth and development of the labrum.23-25

In the normal hip at birth, the femoral head is deeply seated in the acetabulum and held within the confines of the acetabulum by the surface tension of the synovial fluid. It is extremely difficult to dislocate a normal infant hip, even after incising the hip joint capsule.26,27 Hips in newborns with developmental dysplasia are not just normal hips with capsular laxity; they are structurally abnormal.

In the infant, the entire proximal end of the femur, including the greater trochanter, the intertrochanteric zone, and the proximal femur, is composed of cartilage. Between the fourth and seventh months of life, the proximal femoral ossification center appears. The bony centrum and its anlage continue to enlarge until adulthood. The proximal femur and the trochanter enlarge by appositional cartilage cell proliferation.28

The growth areas in the proximal femur are the physeal plate, the growth plate of the greater trochanter, and the femoral neck isthmus.28 A balance among the growth rates of these centers accounts for the normal configuration of the proximal femur, the relationship between the proximal femur and the greater trochanter, and the overall width of the femoral neck. Growth of the proximal femur is affected by the pull of muscles inserting on the proximal femur, forces being transmitted across the hip joint with weightbearing, normal joint nutrition, normal joint circulation, and normal muscle tone.28-31

Normal development and subsequent functioning of the hip joint requires a balanced growth of the acetabular and triradiate cartilages as well as a concentrically reduced femoral head. Experimental animal studies and clinical findings in humans with unreduced hip dislocations suggest that the main stimulus for the concave shape of the acetabulum is the presence of a spherical femoral head.32,33 Harrison and coworkers determined that the acetabulum failed to deepen in area and depth after femoral head excision in rats.33 He also demonstrated atrophy and degeneration of the acetabular cartilage.32

The acetabulum is deepened by the natural pressure from the developing femoral head on the acetabulum.32-33 The depth of the acetabulum is further enhanced at puberty by the development of three secondary ossification centers.27,33,36 The os acetabulum develops in the thick cartilage that separates the acetabular cavity from the pubis. The os acetabulum is the epiphysis of the pubis and forms the anterior wall of the acetabulum. The epiphysis of the ilium, the acetabular epiphysis, forms a major portion of the superior edge of the acetabulum. A third small epiphysis also forms in the ischial region and contributes to its normal growth.

Anatomy

Dysplastic hips often share anatomic abnormalities. The classic dysplastic acetabulum is typically shallow, lateralized, and anteverted.27-42 The coverage is typically deficient anteriorly, laterally, and superiorly. In some cases, the entire pelvis may be underdeveloped. The dysplastic femur has a small femoral head with excessive femoral neck anteversion and a short neck with an increased neck shaft angle.2,43-45 The greater trochanter is often displaced posteriorly and the lesser trochanter assumes a relatively more anterior position. The femoral canal is usually narrow and has been described as a “pipe stem” femur (Fig. 1).

As these bony changes develop, the soft tissues also become abnormal. The abductor muscles become oriented more transversely and therefore function less efficiently. The psoas tendon hypertrophies and the hip capsule thickens. In addition, the hamstrings, adductors, and rectus femoris muscles all shorten.

These pathologic changes result in abnormalities within the hip joint. As the hip joint becomes less stable, the acetabular labrum initially hypertrophies in an attempt to maintain the femoral head within the acetabulum.3 Similarly, the ligamentum teres hypertrophies. If chronic shear stress persists, the labral soft tissue compensation will likely fail, and the labrum can be torn away from the acetabular rim.
resulting in increased contact forces on the cartilage surfaces (Fig. 2).\textsuperscript{3,5,46-50}

Ultimately, these pathologic processes lead to decreased contact area between the femoral head and the acetabulum and lateralization of the center of rotation of the hip. This results in an increased body-weight arm and resultant higher forces transmitted through a smaller surface area, culminating in degenerative hip changes.

**Natural History**

Studies have demonstrated that acetabular dysplasia leads to degenerative changes over time, likely secondary to mechanical factors and related to increased contact stresses.\textsuperscript{51-55} Reduced acetabular size and obliquity create shearing forces on the articular cartilage. These forces lead to chronic overload of the anterior and anterolateral acetabular rim. Eventually, the articular cartilage of the anterior acetabulum and the femoral head fail. Previous reports demonstrate that radiographic degenerative joint disease correlates with the magnitude and length of the excessive pressure.\textsuperscript{54,56}

In 2011, Ross and colleagues published their results of arthroscopy in 73 dysplastic hips undergoing periacetabular osteotomies. A labral tear or chondral degeneration was found in 86% of hips, and 63% of hips demonstrated a hypertrophied labrum. Only 7% of hips were without intraarticular pathology. Labral disease was most common in the anterior (81%) and superolateral (67%) labrochondral junctions. Over two-thirds of patients were found to have acetabular chondromalacia. Acetabular chondral lesions were primarily located at the anterior (76%) and superolateral (84%) labrochondral junctions. Femoral head chondromalacia was seen in only 11% of hips. Sixty-three percent of patients were found to have intraarticular pathology sufficient to require surgical treatment.\textsuperscript{57}

While there is considerable evidence that radiographic acetabular dysplasia leads to secondary degenerative joint disease,\textsuperscript{15,58} there are no predictive radiographic parameters. Cooperman and associates (1983) studied 32 dysplastic hips with lateral center edge angles of less than 20° for more than 20 years in order to determine the natural history of acetabular dysplasia. The investigators found that all patients eventually developed radiographic evidence of degenerative joint disease. Moreover, they determined that none of the conventional radiographic parameters used to describe hip dysplasia were able to predict the rate of the degenerative joint disease.\textsuperscript{54}

**Patient Presentation**

Patients who present with hip pain require a thorough history and physical examination to elucidate the source of their symptoms. Patient factors, including age, overall health, activity level, occupation, and illicit habits, should be identified. In addition, a hip specific history should be taken, including family history of hip problems, any known previous hip disease, and any history of prior hip surgery. Previous hip disease or related treatments, such as childhood and adolescent hip problems, previous hip surgery, hip trauma, and osteonecrosis, may indicate a secondary dysplasia.

Pain characteristics need to be thoroughly evaluated. Patients with hip dysplasia may initially present with mild peritrochanteric pain reflecting abductor fatigue, an almost universal finding in pre-arthrotic hip dysplasia in the mature adult.\textsuperscript{59} Commonly, patients with dysplasia will have groin

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**Figure 2** Arthroscopic images from a patient with hip dysplasia demonstrating the classic hypertrophied labrum (A) and labral tear at the acetabular rim (B).
pain in the affected hip that is worsened with activity.\textsuperscript{59} Similarly, the pattern of symptoms may help elucidate the nature of the dysplasia. Pain worse with weightbearing and activity may indicate underlying joint pathology. Pain with flexion positions or prolonged periods of sitting may commonly be associated with femoroacetabular impingement (FAI). The sensation of locking or catching in the affected joint may indicate intraarticular mechanical problems, such as a labral tear, chondral flap, or loose body.

Nunley and colleagues examined 57 patients with known hip dysplasia. Ninety-seven percent of their patients reported an insidious onset of hip pain without an inciting event. Seventy-two percent of these patients localized their pain to the groin. Eighty-eight percent of patients noted activity related pain with 81\% reporting that their symptoms were exacerbated by walking and 80\% while running. At least one mechanical symptom was reported by 80\% of their patients. Almost half of the studied patients reported a limp. Night pain was also found in more than half of the patients.\textsuperscript{60}

**Physical Exam**

The physical examination of the patient with suspected hip dysplasia should take into account general condition and body habitus, the patient’s sitting posture, and their gait pattern. It is also important to assess for a leg length discrepancy. Standing measurements will allow an assessment of pelvic balance and are therefore considered the best way to assess a leg length discrepancy.\textsuperscript{59,61} Resting lower extremity rotation should be assessed with the patient lying supine on the exam table. Normal lower extremity rotation is between 10° and 30° of external rotation. Abnormal rotation may result from abnormal acetabular version, abnormal femoral version, or femoral head-neck abnormalities.\textsuperscript{59}

Hip range of motion testing is essential for not only diagnosis but also for pre-procedure planning.\textsuperscript{62} The examiner should steady the pelvis with one hand while performing range of motion testing, including hip flexion and internal and external rotation both in 90° of flexion and full extension. In contrast to classic FAI, which may demonstrate abnormal acetabular rim, abnormal femoral version, or femoral head-neck abnormalities.\textsuperscript{59}

Hip range of motion testing is essential for not only diagnosis but also for pre-procedure planning.\textsuperscript{62} The examiner should steady the pelvis with one hand while performing range of motion testing, including hip flexion and internal and external rotation both in 90° of flexion and full extension. In contrast to classic FAI, which may demonstrate restricted hip flexion and internal rotation, patients with classic dysplasia will generally demonstrate normal hip flexion and normal internal rotation.\textsuperscript{47,63,64}

Some special tests may help elucidate the nature of the hip pathology. The anterior impingement test is a special maneuver that is indicative of disorders of the anterior acetabular rim.\textsuperscript{65,66} It is very sensitive for a range of anterior hip lesions, including labral tears and rim fractures, but fairly non-specific for intra-articular disease and joint irritability.\textsuperscript{67} The patient is placed supine, and the affected extremity is passively flexed, adducted, and internally rotated. The test is considered positive if this maneuver reproduces the patient’s pain. Nunley reported that 97\% of the patients in his study had a positive impingement sign.\textsuperscript{60}

The apprehension test is another special maneuver that is useful to assess for anterior hip instability, though it may be positive in patients with labral lesions as well. It is performed by having the patient lie supine on the table. The affected extremity is extended and rapidly externally rotated. The test is considered positive if it elicits apprehension or anterior hip pain.

Finally, patients should be assessed for hip abductor weakness. The Trendelenburg sign is elicited if the patient leans away from the affected extremity during single legged stance on the affected extremity. Nunley reported that 38\% of patients in his study had a positive Trendelenburg sign.\textsuperscript{60} Alternatively, abductor strength can be tested by having the patient lie on his unaffected side and asking him to abduct the leg against resistance.

**Radiology**

The evaluation of a patient with suspected hip dysplasia is confirmed with imaging. The radiographic features of adult hip dysplasia may range from subtle acetabular dysplasia to complete dislocation of the femoral head from the native acetabulum. The goals of imaging are to assess the structural anatomy of the hip, determine the congruency of the articulation, examine the integrity of the joint space, and to assess the soft tissues.\textsuperscript{64} Table 1 describes the commonly used radiographic parameters and measurements used in the diagnosis and categorization of hip dysplasia.

The anterior-posterior (AP) view of the pelvis is the single most important view for defining acetabular dysplasia. It allows for the assessment of acetabular coverage of the femoral head, femoral head sphericity,\textsuperscript{67} the contour of the femoral head-neck junction, the height of the greater trochanter, position of the joint center, the joint space, and Shenton’s line. Lateral radiographs allow better definition of the osseous anatomy of the proximal femur, anterior and posterior joint spaces, and the acetabular rim. Lateral radiographs include the cross table lateral and frog lateral. Also among the lateral views is the false profile view.\textsuperscript{68} This image is obtained by having the patient stand with their foot parallel to the radiographic plate and their pelvis rotated 65° relative to the film. This view constitutes a true lateral view of the acetabulum. It allows measurement of the anterior coverage of the acetabulum, and may also allow better detection of the degenerative changes that tend to begin at the anterior aspect of the joint.

Computer tomography (CT) is a complementary study in evaluating hip dysplasia when dysplastic signs have been recognized on plain films and surgical correction is anticipated. It allows reliable measurements of acetabular coverage, femoral neck anteversion, and the appearance and position of the femoral head.\textsuperscript{69} It also allows better characterization of osseous impingement lesions.\textsuperscript{64}

Magnetic resonance imaging (MRI) is not routinely necessary in hips with obvious structural abnormalities. It may assist in the evaluation of a painful hip in the absence of structural osseous abnormalities and can be useful in the diagnosis of osteonecrosis of the femoral head, stress fracture, neoplasm, or infection. MRI and MRI arthrogram
are useful adjuvants to evaluate the labrum and should be obtained in patients with mechanical symptoms.

**Classification**

Two classification systems are routinely used in describing dysplastic hips. The Tonnis classification groups hips by the degree of secondary osteoarthritis changes.\(^7\) It is useful in planning for osteotomies but is more frequently utilized for research purposes (Table 2).

The Crowe classification describes the degree of femoral head subluxation or dislocation (Table 3).\(^1\) The classification is determined by measuring the vertical distance between the inter-teardrop line and the junction between the femoral head and the medial edge of the neck. The amount of subluxation

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**Table 1** Radiographic Findings in the Evaluation of Hip Dysplasia

<table>
<thead>
<tr>
<th>Radiographic Finding</th>
<th>Description</th>
<th>Implication</th>
</tr>
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<tbody>
<tr>
<td>On AP Pelvis</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Shenton’s Line(^{12,13})</td>
<td>Projected arc from the inferior border of the femoral neck to the superior border of the obturator foramen</td>
<td>A break in the line (arc) reflects superior femoral head subluxation indicative of acetabular dysplasia</td>
</tr>
<tr>
<td>Pistol-Grip Deformity(^{45})</td>
<td>Femoral head extends laterally in a convex shape to the base of the neck</td>
<td>Represents an anterior deformity and hip dysplasia</td>
</tr>
<tr>
<td>Protrusio</td>
<td>Femoral head overlaps the ilioschial line mediially</td>
<td></td>
</tr>
<tr>
<td>Profunda</td>
<td>Floor of the fossa acetabuli touches the ilioschial line</td>
<td></td>
</tr>
<tr>
<td>Crossover Sign(^{134})</td>
<td>The contours of anterior and posterior wall cross medial to the superolateral aspect of acetabulum</td>
<td>Acetabular retroversion</td>
</tr>
<tr>
<td>Projection of Ischial Spine(^{135})</td>
<td>Projection of ischial spine</td>
<td>Increased retroversion</td>
</tr>
<tr>
<td>Lateral Center Edge Angle(^{56})</td>
<td>Angle between horizontal line through center of both femoral heads and a line from center of femoral head to most superolateral point of acetabulum</td>
<td>Assesses the superior and lateral coverage of the femoral head by the bony acetabulum</td>
</tr>
<tr>
<td>Tonnis Angle(^{136})</td>
<td>Angle between horizontal line through both femoral heads and a line from the most medial point of the weightbearing acetabulum to the most lateral point of the acetabulum</td>
<td>Evaluates orientation of acetabular roof or inclination of the sourcil</td>
</tr>
<tr>
<td>Acetabular Angle of Sharp(^{137})</td>
<td>Angle between horizontal line through both inferior teardrop and a line from the inferior aspect of the teardrop to the superolateral aspect of the acetabulum</td>
<td>Measures the acetabular inclination or opening</td>
</tr>
<tr>
<td>Femoral Head Coverage</td>
<td>Distance between a line through most medial aspect of the joint space and align through the lateral aspect of the acetabulum, divided by the distance between a line through the most medial aspect of the joint space and a line through the most lateral aspect of the head</td>
<td>Measures the percentage of the femoral head covered by the bony acetabulum</td>
</tr>
<tr>
<td>Neck Shaft Angle</td>
<td>Angle between the axis of the femoral shaft and the axis of the neck passing through the femoral head center</td>
<td>Evaluates the angle of the femoral neck</td>
</tr>
<tr>
<td>On False Profile View</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Vertical Center Anterior Angle(^{48})</td>
<td>Angle between a vertical line through the center of the femoral head and an oblique line running from the center of the head to the most anterior point of the acetabulum</td>
<td>Evaluates the anterior and superior coverage of the femoral head</td>
</tr>
<tr>
<td>Computed Tomography</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Anterior Acetabular Sector Angle (\text{AASA})/Posterior Acetabular Sector Angle (\text{PASA})</td>
<td>Angle between a line formed through center of femoral heads and an oblique line from the center of the head to the most anterior portion of the acetabulum to determine the AASA and to the most posterior portion of the acetabulum to determine the PASA</td>
<td>Describes the relationship between the femoral head and the acetabulum. These values are decreased in acetabular dysplasia</td>
</tr>
<tr>
<td>Femoral Neck Version</td>
<td>Angle between the femoral neck and the posterior aspect of femoral condyles</td>
<td>Evaluates the version of the femur</td>
</tr>
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is the ratio between this distance and the vertical diameter of the normal femoral head. This classification system can be used to guide treatment algorithms for patients being considered for total hip arthroplasty.

Table 2  Tonnis Classification of Hip Dysplasia

<table>
<thead>
<tr>
<th>Grade</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>No arthritic changes</td>
</tr>
<tr>
<td>1</td>
<td>Sclerosis, mild joint space loss, minimal osteophyte formation</td>
</tr>
<tr>
<td>2</td>
<td>Small cystic changes with moderate joint space loss</td>
</tr>
<tr>
<td>3</td>
<td>Large cysts and moderate to complete joint space loss</td>
</tr>
</tbody>
</table>

Table 3  Crowe Classification of Hip Dysplasia

<table>
<thead>
<tr>
<th>Type</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>I</td>
<td>Subluxation &lt; 50% of vertical diameter of femoral head</td>
</tr>
<tr>
<td>II</td>
<td>Subluxation of 50% to 75% of vertical diameter of femoral head</td>
</tr>
<tr>
<td>III</td>
<td>Subluxation of 75% to 100% of vertical diameter of femoral head</td>
</tr>
<tr>
<td>IV</td>
<td>Proximal migration of &gt; 100% of vertical diameter of femoral head</td>
</tr>
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</table>

Treatment

Hip Arthroscopy

Hip arthroscopy is an option for the treatment of mild hip dysplasia. This technique can address mechanical symptoms, loose bodies, labral tears, chondral defects, and synovial disease (Fig. 2). However, it is limited in that it does not address the osseous abnormalities of the dysplastic hip that are the underlying cause of the mechanical symptoms.

Several investigators have looked at the outcomes of dysplastic hips treated with hip arthroscopy. Byrd and Jones published a report in 2003 of 48 patients who underwent hip arthroscopy for intraarticular pathology and were retrospectively determined to have acetabular dysplasia. The investigators found that 67% of the hips had labral lesions, and 60% had chondral lesions that were addressed at the time of surgery. Patients were followed for an average of 27 months, and the investigators found that all patients had improved Modified Harris Hip Scores at final follow-up.

In contrast, Parvizi and colleagues published a report in 2009 in which they described the outcomes in 36 dysplastic hips treated with hip arthroscopy. Byrd and Jones published a report in 2003 of 48 patients who underwent hip arthroscopy for intraarticular pathology and were retrospectively determined to have acetabular dysplasia. The investigators found that 67% of the hips had labral lesions, and 60% had chondral lesions that were addressed at the time of surgery. Patients were followed for an average of 27 months, and the investigators found that all patients had improved Modified Harris Hip Scores at final follow-up.

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While hip arthroscopy alone has limited applicability in the treatment of hip dysplasia, it is a useful adjuvant treatment when combined with bony reconstructive procedures. Acetabular dysplasia typically results in intraarticular pathology, and hip arthroscopy may provide an opportunity to address this pathology. Kim and colleagues published their results of combined hip arthroscopy and periacetabular osteotomy. They found that 88% of their patients had a labral lesion. All patients with labral lesions underwent arthroscopic labral debridement at the time of arthroscopy. The mean Harris Hip Score improved from 72.4 preoperatively to 94 at a mean of 74 months.

Osteotomies

Osteotomies are useful in the treatment of hip dysplasia as they can address the underlying morphologic abnormality. They can reorient the articular surfaces of the hip joint and allow load transmission through a broader surface area, subjecting the joint to less force. Osteotomies can also medialize the center of hip rotation and as a result decrease the joint reactive forces. These changes can reduce pain, protect the articular cartilage, and improve the functional arc of motion. These procedures are generally indicated in young patients with symptomatic hip dysplasia without excessive proximal migration of the hip center of rotation, who have preserved range of motion and no more than mild degenerative changes.

Osteotomies about the hip joint can be carried out at the acetabulum, at the proximal femur, or using some combination of both. Pelvic osteotomies address the location of
the primary pathology. They correct the major anatomic abnormality and do not create a secondary deformity, which can affect future reconstructive procedures. The femoral osteotomy can be added if significant femoral deformity exists; however, it is rarely indicated as an isolate procedure in patients with acetabular dysplasia.

**Pelvic Osteotomies**

Pelvic osteotomies can be categorized into two types: reconstructive and salvage. Reconstructive osteotomies are intended to restore normal hip anatomy and biomechanics. They improve symptoms and possibly prevent degenerative changes. These types of osteotomies require a hip joint in which the femoral head and the acetabulum are congruent. Salvage osteotomies are used to relieve pain when the articular surface congruency cannot be restored. These osteotomies are performed in patients who have a hip joint in which the femoral head and the acetabulum are not the same shape (Fig. 3).

Various periacetabular osteotomies have been developed to reorient the hyaline cartilage of the hip in mature patients. Salter’s innominate osteotomy was first used in mature hips more than 50 years ago. It proved useful in the treatment of mild dysplasia but was inconsistent in major acetabular reorientation. More consistent major acetabular reorientation was introduced independently in Germany and Japan with spherical osteotomies. This technique allows excellent femoral head coverage, but medialization of the joint center can be difficult. Other complex osteotomies were subsequently introduced by Tonnis and Steel.

In 1988, Ganz and colleagues introduced the Bernese periacetabular osteotomy. This procedure, which is also known as a “Ganz osteotomy,” allows both redirection of the acetabulum and medialization of the hip joint center. The fundamental goal of this procedure is to correct the acetabular insufficiency and improve femoral head coverage by repositioning the weightbearing surface laterally and anteriorly. Secondary goals include improved hip stability and medialization of the hip center of rotation.

The ideal patient for these procedures is one with a symptomatic structural abnormality, a congruent joint, and the absence of advanced secondary arthritis. These patients also need to have a well-maintained hip range of motion. These osteotomies are contraindicated in patients with excessive posterior wall coverage. These patients require a surgical dislocation in order to adequately address their deformities.

Patients with advanced cartilage degeneration anteriorly also should not undergo this procedure as the degenerative area will wind up in the weightbearing zone after osteotomy.

There are numerous advantages to the periacetabular osteotomy as a treatment for hip dysplasia. The Ganz osteotomy is generally performed through a modified Smith Peterson approach, and this abductor sparing dissection through a single incision decreases the risk of postoperative gait abnormalities. The osteotomy utilizes straight, reproducible, extra-articular cuts that preserve the posterior column and do not change the shape of the true pelvis. The osteotomy also allows major multi-planar corrections, including lateral and anterior rotation and medialization of the hip joint. This approach preserves the acetabular fragment blood supply, provides reliable healing, and allows for accelerated rehabilitation. Most importantly, this intervention is a joint preserving treatment.

The Ganz osteotomy is performed from the inner aspect of the pelvis and generally consists of three cuts: a partial osteotomy of the ilium, a complete osteotomy of the pubis, and a partial osteotomy of the ischium. The remaining bone of the ischium is used to support the osteotomy site. The osteotomy is performed through a modified Smith Peterson approach, and this abductor sparing dissection through a single incision decreases the risk of postoperative gait abnormalities. The osteotomy utilizes straight, reproducible, extra-articular cuts that preserve the posterior column and do not change the shape of the true pelvis. The osteotomy also allows major multi-planar corrections, including lateral and anterior rotation and medialization of the hip joint. This approach preserves the acetabular fragment blood supply, provides reliable healing, and allows for accelerated rehabilitation. Most importantly, this intervention is a joint preserving treatment.

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and a biplanar osteotomy of the ilium. The osteotomized acetabulum is then displaced medially, rotated anteriorly, and rotated laterally. The osteotomy is then secured with several screws. Postoperative radiographs are used to assess the adequacy of the correction.

Acetabular osteotomies address the underlying bony abnormality, but most patients will have intraarticular pathology at the time of presentation. Most investigators recommend opening the joint and evaluating for labral lesions as well as impingement between the anterior femoral neck and anterior acetabulum. An anterior arthrotomy performed in association with a PAO allows resection of anterior labral tears and limited femoral neck osteoplasty. However, joint exposure is limited unless an extensive abductor dissection is performed. Other investigators have suggested either simultaneous or staged hip arthroscopy to assess and treat the intraarticular pathology.

Several studies have reported on outcomes after periacetabular osteotomies. In 2011, Nunley and colleagues reported their outcomes with PAOs in 65 hips with symptomatic hip dysplasia at an average of 27 months. They found an improvement in mean Modified Harris Hip Scores from 66.4 to 91.7 at final follow-up. Only one hip in their series required conversion to a total hip arthroplasty. One hip required revision for symptomatic femoral-acetabular impingement. Postoperative radiographs demonstrated consistent correction, including improved femoral head coverage and improved acetabular inclination.

In the longest follow-up study published to date, the Bern group reported their long-term outcomes with the Bernese periacetabular osteotomy. When evaluating the first 75 hips in which they performed the procedure at the 20-year follow-up, they found that 40% had gone on to require total hip arthroplasty or fusion at an average of 12 years after the index procedure. The group also identified several factors as predictive of a poor outcome: older age at surgery, positive anterior impingement test, limp, higher osteoarthritis grade, and postoperative extrusion index.

Though results with the Ganz osteotomy tend to be favorable, complications can arise. Excess posterior coverage can be caused by excessive anteverision of the osteotomy. This can lead to posterior acetabular impingement and limited extension and external rotation. The osteotomy can also be malpositioned anteriorly, resulting in an acetabular index of less than zero, which may result in secondary anterior impingement.

In patients with severe acetabular dysplasia that do not have a congruent joint, but have minimal arthritic changes, a redirection osteotomy cannot correct their abnormal morphology. These patients may be candidates for a salvage osteotomy. The two most commonly performed salvage osteotomies are shelf procedures and the Chiari osteotomy.

Shelf procedures generally use corticocancellous graft to augment the anterolateral portion of the acetabulum. The graft is inserted into a slot created above the acetabulum and acts as a buttress to increase joint stability and increase the weightbearing surface of the acetabulum. This procedure does not change the relationship of the femoral head to the true acetabulum, nor does it medialize the hip center of rotation.

The Chiari osteotomy is recommended for patients with inadequate femoral head coverage and an incongruous joint. An osteotomy is made above the acetabulum and extends into the sciatic notch. By abducting the hip, the distal portion of the osteotomy moves medially, shifting the ilium laterally beyond the edge of the acetabulum. The procedure thus medializes the hip center. The interposited capsule undergoes metaplasia and becomes fibrocartilage over time.

**Femoral Osteotomies**

Proximal femoral osteotomies have been used in the treatment of hip dysplasia for approximately a century with a varus osteotomy to correct the coxa valga and a distal transfer of the greater trochanter to correct for trochanteric overgrowth. However, proximal femoral osteotomies along are rarely useful in stabilizing hips with acetabular dysplasia in skeletally mature patients. They are useful when the femur is the primary source of deformity or when the pelvic osteotomy alone provides insufficient correction.

In order to perform an isolated proximal femoral osteotomy, several criteria need to be met: the osteotomy must completely correct the deformity, the patients must have a functional arc of motion, the joint needs to congruent, and placing the hip in the position of proposed correction should provide comfort to the patient. This situation is generally only found in patients with coxa valga and mild acetabular dysplasia.

**Hip Arthrodesis**

In patients with severe unilateral hip dysplasia and who are poor candidates for osteotomies or total hip replacement, an arthrodesis may be considered. However, currently, these procedures are rarely indicated. Arthrodesis may provide good pain relief for patients with severe unilateral disease; however, this procedure will limit a patient’s physical activities and can lead to progressive degenerative changes in the ipsilateral knee and lower back.

The ideal position for hip arthrodesis is neutral abduction, external rotation of 0° to 30°, and 20° to 25° of flexion. It is essential to avoid abduction and internal rotation in order to minimize excessive lumbar spine and contralateral knee motion. Contraindications to performing a hip arthrodesis include morbid obesity, systemic arthritis, contralateral hip dysfunction, lumbosacral spine disease, or ipsilateral knee abnormalities.

**Pelvic Support Osteotomy**

Another option for treatment of severe hip dysplasia is a resection of the femoral head with valgus-producing pelvic support osteotomy (Fig. 4). This treatment is generally reserved for patients with severe pain and low functional
demands, such as those with underlying neuromuscular disorders or poor medical conditions.

The goals of this procedure are to create and abduction and extension effect in the femur at the level of the ischium to increase the range of abduction, support the femur on the pelvis, to reduce lumbar lordosis, and to prevent a Trendelenburg limp by tightening the gluteus medius muscle as the distance of the greater trochanter from the pelvis is increased.\textsuperscript{111-113} The disadvantages of this procedure include the limb length inequality it produces, overall lower extremity weakness, the need for ambulatory aids, increased oxygen consumption with ambulation, and decreased gait velocity.\textsuperscript{112,114}

A Japanese group reported on their 20-year follow-up of 53 patients who had undergone 58 pelvic support osteotomies for osteoarthrosis of a dysplastic hip. Thirty-five percent of these patients underwent total hip arthroplasty at an average of 14 years after the index procedure (range: 7 to 24 years), and only one patient required corrective varus osteotomy to pass the stem. The Kaplan Meier’s survivorship was 66% at 10 years and decline to 38% and 19% at 15 and 20 years, respectively.\textsuperscript{103}

**Total Hip Arthroplasty**

Despite the availability the recent advances in joint-preserving techniques, many patients with hip dysplasia present with advanced degenerative disease that is not amenable to joint preservation surgery.\textsuperscript{9,115} Because of the anatomic abnormalities associated with hip dysplasia and the younger mean age of patients with this diagnosis who go on to require arthroplasty, special considerations need to be made when considering total hip arthroplasty (THA) in this population. In the very young patient, the long-term implications of performing a THA make secondary goals like bone and muscle preservation and prolonged implant durability almost as important as the primary goal of pain relief.\textsuperscript{115}

Abductor deficiency is a common problem in patients with severe hip dysplasia. As the greater trochanter becomes displaced posteriorly and the neck shaft angle decreases, the abductor lever arm becomes oriented more transversely. This abductor deficiency can result in serious complications after a THA, including high rates of dislocation\textsuperscript{116} and chronic limp.\textsuperscript{115}

Deficient acetabular bone may limit the surgeon’s ability to place the acetabular component fully on native bone in the true acetabular region (Fig. 5). Three common alternative methods to reconstruct dysplastic acetabuli have been described: augmentation with bone grafting, a high hip center, or medialization of the cup.

Acetabular augmentation with structural grafting of the deficient acetabulum in combination with placing the component in its anatomic position has some desirable features. Autograft bone is readily available by using the patient’s own femoral head, the hip center can be restored to a biomechani-

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**Figure 4** A 14-year-old male with neglected congenital hip dislocation (A). After proximal femoral valgus osteotomy and distal femoral varus osteotomy with lengthening (B).
cally normal position, and bone grafting may increase bone stock.\textsuperscript{117,118} There are also disadvantages to this technique, including that bone grafting increases the complexity of the procedure, and when a large amount of the component is supported by the graft, there is a risk of long-term graft resorption and collapse, leading to cup failure.\textsuperscript{119}

Purposefully creating a high hip center or placing the component superiorly allows the component to be covered more completely by native bone, which facilitates biologic fixation and avoids the need for bone grafting.\textsuperscript{120,121} It also requires smaller acetabular components with thinner polyethylene liners, does not increase acetabular bone stock, affords a limited amount of leg lengthening, and leads to abnormal hip biomechanics. The high hip center needs to be high and medial, or it will fail early.

A third alternative for acetabular reconstruction is medialization of the acetabular component by internally overreaming or deliberate fracture of the medial wall of the acetabulum.\textsuperscript{122,123} This technique provides increased lateral coverage of the acetabular component by native iliac bone and decreases joint reactive forces through medialization of the hip center of rotation. Its main disadvantages include the loss of medial bone stock and the risk of early catastrophic acetabular component migration.

For the femoral component, a proximally coated monolithic stem can be used in mild dysplasia. However, for more marked deformities, extensively coated stems or modular stems may be required. Moreover, a subtrochanteric or metaphyseal osteotomy may be required in more severely dysplastic cases. A subtrochanteric osteotomy allows both shortening and correction of the rotational abnormalities while preserving the metaphysis (Fig. 6).\textsuperscript{124-126} The resected bone may then be used as an onlay autograft.

Several studies have addressed the outcomes in patients undergoing total hip arthroplasty for hip dysplasia.\textsuperscript{123,127-131} Pain relief in patients with hip dysplasia undergoing total hip arthroplasty parallels the excellent results of total hip arthroplasty in the general population.\textsuperscript{115,123,127-129} Notable overall improvements in hip scores were also reported in most series.\textsuperscript{127-131}

Patients with very stiff hips preoperatively may have residual postoperative stiffness. Functional results tend to be excellent in patients with Crowe I and II dysplasia but are less good in patients with Crowe III and IV disease. Patients with Crowe III and IV dysplasia tend to have a persistent limp with a waddling gait, as well as a higher rate of aseptic

Figure 5 Deficient acetabular bone may limit the surgeon’s ability to place the acetabular component fully on native bone in the true acetabular region.

Figure 6 A. A patient with bilateral Crowe 4 hip dysplasia. B. Status bilateral total hip arthroplasties with modular stems and subtrochanteric shortening osteotomies.
loosening and mechanical failure than the general population undergoing total hip arthroplasty.

**Conclusion**

The treatment of hip dysplasia in adult patients is based on the degree of dysplasia and the amount of concomitant arthritis. Patients with mild dysplasia who are asymptomatic can be observed. Those with mechanical symptoms alone can undergo arthroscopy with close follow-up. Patients with moderate to severe dysplasia and minimal arthritis are candidates for reconstruction. Those patients with moderate to severe arthritis can undergo a salvage procedure, such as arthrodesis or pelvic support. However, a vast majority of these patients are best served with a total hip arthroplasty (Fig. 7).

**Disclosure Statement**

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