CQ HAND + UPPER LIMB
SPECIALIST ORTHOPAEDIC SURGEON

EVIDENCE SUMMARY

Hip dysplasia (adult)

Overview

DEFINITION AND PATHOPHYSIOLOGY

- Developmental dysplasia of the hip (DDH) refers to a spectrum of pathologic conditions involving the developing hip, ranging from acetabular dysplasia to complete dislocation of the hip [14].
- Deficient anterolateral acetabular coverage of the femoral head is the dominant deformity in adult hip dysplasia, resulting in structural hip instability and acetabular rim overload [28].
- Significant hip deformity resulting from childhood conditions such as developmental dysplasia of the hip can lead to secondary hip osteoarthritis in adult life [2].
- Many patients previously thought to have primary or idiopathic osteoarthritis of the hip are now believed to have had hip impingement leading to osteoarthritis over time [2].
- The goal of hip preservation surgery in dysplasia is to alter hip joint morphology to allow more unhindered physiologic range of motion while optimizing hip joint mechanics to delay or halt the progression of hip osteoarthritis [2].

EPIDEMIOLOGY AND RISK FACTORS

- DDH is the most common disorder of the hip in children, with 1 in 1,000 children (0.1%) born with a dislocated hip and 10 in 1,000 children (1%) born with hip subluxation or dysplasia [14].
- Eighty percent of children affected by DDH are female [14].
- The left hip is more commonly involved (60%) than the right, and bilateral involvement occurs in 20% of cases [14].
- The etiology of DDH is unknown but is thought to be multifactorial, involving genetic, hormonal, and mechanical factors [14].
- Risk factors for DDH include female sex, firstborn status, breech presentation, and disorders of intrauterine packing such as congenital dislocation of the knee, congenital muscular torticollis, and metatarsus adductus [14].
- In affected children, 12% to 33% have a family history of DDH [14].

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- The risk of DDH is 6% with one affected sibling, 12% with one affected parent, and 36% with a parent and sibling affected [14].

CLINICAL PRESENTATION

- In the neonatal period, the key clinical finding for DDH is instability of the hip [14].
- Hip clicks are nonspecific physical findings in the evaluation of DDH [14].
- Asymmetric skin folds are an unreliable and nonspecific finding in the evaluation of DDH [14].
- In infants older than 6 months, common findings for DDH are asymmetric hip abduction and apparent limb shortening in unilateral dislocations [14].
- Toddlers with bilateral hip dislocations often present with hyperlordosis of the lumbar spine [14].
- Adolescents with DDH may manifest fatigue and pain in the hip, thigh, or knee [14].
- A decrease in hip abduction is the most sensitive test result for DDH on range of motion testing [14].
- The Galeazzi test is positive when the knee on the involved side is lower than the contralateral knee with hips and knees flexed to 90°, indicating unilateral subluxation or dislocation [14].
- The Barlow test is positive when the hip on the affected side subluxates or dislocates upon application of a gentle posterolateral force with the hip flexed and adducted [14].
- The Ortolani test is positive when the dislocated hip is reducible, often accompanied by a palpable clunk as the femoral head reduces into the acetabulum [14].

IMAGING AND DIAGNOSIS

- Conventional radiographs remain critical in the initial imaging evaluation of the hip for conditions including DDH [5].
- A complete hip series usually consists of an anterior-posterior (AP) pelvis, a centered AP hip, a lateral view (frog-leg, cross-table, Dunn 45° or 90°), and a false-profile (Lequesne) view [5].
- The Tönnis angle is defined by the angle of the acetabular sourcil and a line parallel to the transverse pelvis axis, with values between 0° and 10° considered normal [5].
- The lateral center-edge angle (Wiberg) is the angle between a line from the center of the femoral head perpendicular to the transverse pelvis axis and a second line from the center of the femoral head to the superolateral most point of the acetabulum [5].
- Center-edge angles of 20°–40° are considered normal, while angles from 20° to 25° are considered borderline [5].
- The femoral head extrusion index is defined by the length of the femoral head that lies beyond the acetabulum as a percentage of the total horizontal width of the femoral head, with values greater than 25% considered abnormal [5].
- In the first 4 to 6 months of life, ultrasonography can help confirm a diagnosis of DDH because radiographic evaluation is often unreliable as the femoral epiphysis has not yet ossified [14].
- On ultrasonography, a normal α angle is greater than 60° and a normal β angle is less than 55° after age 4 to 6 weeks [14].

- The acetabulum should cover more than 50% of the femoral head on ultrasonography [14].
- Magnetic resonance imaging (MRI) is commonly the modality of choice for confirming reduction in DDH treatment due to the lack of radiation and greater ability to visualize the cartilaginous femoral head and other soft tissues [10].
- Gadolinium-enhanced MRI may be predictive of osteonecrosis and allow the surgeon to revise reduction or cast positioning at the same visit [10].
- Recent recognition of deposition of gadolinium-based contrast agents in the basal ganglia has increased concern about their use in the developing brain [10].
- Delayed gadolinium-enhanced MRI of cartilage (dGEMRIC) assessment of glycosaminoglycan (GAG) content is predictive of outcome after periacetabular osteotomy, with low GAG content associated with increased risk of failure [28].

SURGICAL TREATMENT

- Periacetabular osteotomy (PAO) is indicated for symptomatic younger patients with spherically congruent dysplasia of the hip, a lateral center-edge angle of less than 20 degrees, and minimal or no secondary arthritic changes (Tönnis grade 0 or 1) [78].
- Symptomatic patients with weight-bearing, activity-related pain and center-edge angles between 20 and 25 degrees, particularly women with coxa valga and excessive anteversion, may be reasonable surgical candidates for PAO [78].
- Preoperative age older than 35 and fair or poor joint congruence are independent factors predictive of failure of PAO [78].
- When preoperative age older than 35 and fair or poor joint congruence occur together, the chance of resultant severe pain or conversion to total hip replacement reaches 95% [78].
- The Bernese PAO has been popularized for acetabular reorientation and is now a mainstay of surgical treatment for adult hip dysplasia [28].
- The Bernese PAO is performed through a modified Smith-Petersen interval with ASIS osteotomy and is now commonly rectus-sparing [28].
- Advantages of the Bernese PAO include a single surgical incision, preservation of blood supply to the acetabulum, maintenance of posterior column integrity, and the ability to perform major multidimensional precise acetabular correction [28].
- Disadvantages of the Bernese PAO include anterior overcorrection producing acetabular retroversion and associated secondary femoroacetabular impingement, intra-articular fracture, and neurovascular injury [28].
- Reported survival for PAO is 60% at 20-year follow-up [28].
- Preservation of the hip after PAO has been achieved in 73% to 76% of patients in two mid-term studies with longer than 9-year average follow-up [30].
- The 30-year survivorship of the first 75 PAOs done at the originating center in Berne has been reported as 29% [30].

- Factors identified as likely to negatively impact the result of PAO for dysplasia include advancing age, moderate preoperative arthritis, labral pathologic processes, postoperative impingement, and fair or poor congruence of the joint [30].
- Intertrochanteric osteotomy of the proximal femur is occasionally done as a simultaneous procedure with PAO to correct excessive valgus and anteversion of the proximal femur [78].
- Valgus osteotomy can be done for coxa vara and aspherical Perthes type femoral head deformity to maintain articular congruence and avoid impingement of the greater trochanter with the rotated acetabular rim [78].
- Salvage osteotomies such as the Chiari osteotomy rely on the articulation of the femoral head with metaplastic fibrocartilage rather than articular hyaline cartilage [28].
- The Salter innominate osteotomy redirects the entire acetabulum so that its roof covers the femoral head anteriorly and superiorly [82].
- Prerequisites for the success of the Salter innominate osteotomy include the femoral head being positioned opposite the level of the acetabulum, release of iliopsoas and adductor muscle contractures, complete and concentric reduction of the femoral head into the true acetabulum, reasonable joint congruence, and good range of motion especially in abduction, internal rotation, and flexion [82].
- Structures at risk of injury during a Salter innominate osteotomy include the lateral femoral cutaneous nerve, nutrient vessels to the tensor fasciae latae muscle, sciatic nerve, obturator nerve, and femoral nerve [82].

Anatomy & Pathophysiology

BONY ANATOMY

- The hip is a multiaxial joint formed by the articulation between the pelvis and femur, connecting the axial skeleton and the lower extremity [35].
- The hemipelvis comprises three bones—the ilium, ischium, and pubis—which unite at the triradiate cartilage within the concave acetabulum [35].
- The shape and depth of the acetabulum are formed by the appearance of ossification centers around the end of the first decade of life, with complete fusion occurring around 18 to 19 years of age [35].
- The acetabulum comprises an articular crescent-moon–shaped lunate surface and a nonarticular central fossa that serves as the attachment point for the ligamentum teres [35].
- The acetabulum is incomplete inferiorly, forming a notch through which vital blood vessels and nerves pass to supply the joint [35].
- The femoral head forms two-thirds of a sphere, with a small depression at its center from which the ligamentum teres extends to connect to the acetabular notch [35].
- The neck-shaft angle of the femur averages 125°, which allows for greater mobility by placing the head and neck more perpendicular to the acetabulum in a neutral position [35].
- Normal version, defined as the head-neck angle in the frontal plane, averages 15 to 20° [35].

- The mean femoral neck-shaft angle in the adult is 130° ± 7° [40].
- The mean anteversion of the femoral neck is 10° ± 7° [40].
- The two prime trabecular groups of the proximal femur are the principal tensile group and the principal compressive group [40].
- The weakest area in the femoral neck is located in the Ward triangle [40].
- The calcar femorale is a medial area of dense trabecular bone that transfers stress from the femoral shaft to the inferior portion of the femoral neck [40].

SOFT TISSUE ANATOMY

- The acetabular labrum is a fibrocartilaginous ring attached to the rim of the acetabulum that extends the articulating surface area and increases femoral head coverage [35].
- The labrum is triangular in cross section, which contributes to its ability to create a pressurized seal of the central compartment of the hip during loading [35].
- Only the external one-third of the labrum contains blood vessels, leaving the majority of the structure avascular and limiting its healing ability following injury [35].
- The labrum is highly innervated, with the presence of both mechanoreceptors and nociceptors [35].
- The labrum is absent in the area of the inferior acetabular notch, where the transverse acetabular ligament serves as the continuation of the labrum [35].
- The hip is surrounded by a dense fibrous capsule extending from the periphery of the acetabulum to the intertrochanteric line of the femoral neck [35].
- The capsule enhances joint stability by preventing translation of the femoral head in the acetabulum [35].
- The iliofemoral ligament is Y-shaped and is the thickest and strongest of the three main ligaments supporting the hip [35].
- The iliofemoral ligament functions to limit external rotation, while its lateral arm limits extension of the joint [35].
- The ischiofemoral ligament extends from the ischial margin of the acetabulum to the greater trochanter of the femur and restricts internal rotation motion [35].
- The pubofemoral ligament extends from the obturator crest of the pubic bone to the femoral neck and acts to limit abduction of the joint [35].
- Deep fibers from all three main ligaments merge to form the zona orbicularis, which circumvents the femoral neck [35].
- The ligamentum teres originates in the cotyloid fossa and attaches on the fovea of the femoral head [36].
- The ligamentum teres transmits an arterial branch of the posterior division of the obturator artery to the femoral head, which is less significant in adults [32].
- The hip capsule attaches anteriorly and posteriorly along the periphery of the acetabulum outside the labrum [36].

- The hip capsule attaches to the femur anteriorly along the intertrochanteric crest, while on the posterior side it attaches only partially, leaving the basicervical region of the femoral neck and intertrochanteric region extracapsular [36].
- The iliofemoral ligament becomes taut in full extension, preventing anterior dislocation and hyperextension of the hip [36].
- The twisted orientation of the hip ligaments provides a screw mechanism for the hip in full extension [36].

VASCULAR ANATOMY

- From birth to approximately 4 years of age, the major blood supply to the femoral head comes from the medial and lateral femoral circumflex arteries, with major contributions from the artery of the ligamentum teres [43].
- From the age of 4 years to adulthood, the posterosuperior and posteroinferior retinacular arteries from the medial circumflex artery are the major blood supply to the femoral head [43].
- In adulthood, the major blood supply to the femoral head is from the medial femoral circumflex and lateral epiphyseal arteries [43].
- The medial femoral circumflex artery is the main blood supply to the femoral head and terminates in the posterior aspect of the extracapsular arterial ring [40].
- The lateral group of ascending branches from the extracapsular arterial ring is the main blood supply to the femoral head [40].
- The lateral epiphyseal artery penetrates the femoral head and is believed to be the dominant blood supply to the femoral head from the ascending cervical artery system [40].
- The artery of the ligamentum teres arises from either the obturator or medial femoral circumflex artery and does not provide sufficient blood supply to maintain the viability of the femoral head [40].

PATHOPHYSIOLOGY OF DEVELOPMENTAL DYSPLASIA

- Developmental dysplasia of the hip (DDH) is a condition characterized by a developmental anomalous anatomical relationship between the femoral head and the acetabulum [12].
- The normal development of the acetabulum depends on the concentric centralization of the femoral head into the acetabular cavity, with the presence of articular motion [12].
- Minimal femoral head displacement from the center of the acetabular cavity may predispose to abnormal acetabular development and further instability [12].
- In the subluxated hip, asymmetric pressure causes progressive flattening of the posterior and superior acetabular rim and medial femoral head [24].
- In the completely dislocated hip, dysplasia occurs because normal joint development requires concentric motion with normally mated joint surfaces [24].
- The shallow, deformed dysplastic joint surfaces predispose to further mechanical instability and the inexorable progression of the disorder [24].

- DDH is a gradually progressive disorder associated with distinct anatomic changes, many of which are initially reversible [37].
- In unstable hips at birth, the posterosuperior rim of the acetabulum loses its sharp margin and becomes flattened and thickened in the area over which the femoral head slides [37].
- A ridge of thickened articular cartilage called the neolimbus arises along the posterosuperior acetabular wall as the femoral head slides in and out of the socket [37].
- In hips that remain dislocated, the fatty tissue known as the pulvinar thickens in the depths of the acetabulum and may impede reduction [37].
- The ligamentum teres elongates and thickens in dislocated hips, taking up valuable space within the acetabulum [37].
- The inferior capsule of the hip assumes an hourglass shape in dislocated hips, eventually presenting an opening smaller in diameter than the femoral head [37].
- The iliopsoas tendon is pulled tight across the capsular isthmus in dislocated hips, contributing to narrowing and acting as a barrier to closed reduction [37].
- The femoral changes in dislocated hips include an increase in anteversion and some flattening of the femoral head as it lies against the ilium [37].
- The natural history of DDH presents via three evolutional courses: spontaneous resolution, progression to subluxation or dislocation, or persistent subclinical instability with acetabular dysplasia [12].
- It is unclear whether acetabular dysplasia diagnosed during adolescence or later is a residual deformity of childhood DDH or a distinct acetabular growth abnormality with later presentation [12].
- Late dysplasia is more likely to be bilateral than childhood DDH [12].

BIOMECHANICS AND DEGENERATION

- Hip dysplasia is characterized by a shallow acetabulum with deficient coverage of the femoral head [65].
- A shallow, more vertical acetabulum leads to increased edge loading, decreased contact areas, and increased contact pressures [65].
- The dysplastic hip is inherently unstable, leading to adaptive changes including labral and iliocapsularis muscle hypertrophy and abductor fatigue in an attempt to stabilize the femoral head [65].
- Instability and excessive stress on the articular cartilage in dysplastic hips ultimately lead to osteoarthritis if left untreated [65].
- Joint loading forces are concentrated at the edge of the dysplastic acetabulum and labrum, leading to chondrolabral damage [58].
- DDH results in decreased anterolateral acetabular coverage of the femoral head, lateralization of the hip center, and eccentric joint loading that can result in progressive joint degeneration [22].
- The proximal femur is often involved in DDH, with asphericity of the femoral head, head-neck offset malformations, and increased femoral anteversion potentially present [22].
- Subtle deformities of the hip from childhood, such as the “tilt deformity” or “pistol grip” deformity of the proximal femur, have been implicated in the development of osteoarthritis [2].

- Periacetabular osteotomy for treatment of painful hip dysplasia in young adults appears to be effective in delaying prosthetic hip reconstruction when surgical intervention occurs while arthritic progression is fairly mild [2].
- The articular damage resulting from hip impingement can occur while symptoms remain relatively mild and intermittent, arguing for early intervention before the onset of irreversible arthritis [2].
- In a 2017 study of 162 patients aged 55 years and older, the probability of undergoing total hip arthroplasty in 10 years based on hip morphology was approximately one in three for dysplasia of the hip [16].
- In the same study, the probability of undergoing total hip arthroplasty in 20 years was approximately two in three for dysplasia of the hip [16].
- Radiographic variables with negative prognostic value for hip osteoarthritis include femoral head lateralization greater than 8 mm, femoral head extrusion index greater than 0.2, acetabular depth-to-width index less than 0.3, lateral center-edge angle less than 25°, and Tönnis angle greater than 8° [16].
- Acetabular dysplasia describes a shallow hip socket without frank dislocation of the femoral head but with varied degrees of superior lateral subluxation [57].
- The shallow hip socket in acetabular dysplasia results in high articular cartilage contact stresses near the superolateral rim of the acetabulum, with concurrent labral tears and progressive lateral subluxation of the femoral head [57].
- Osteotomies of the pelvis, such as the Bernese periacetabular osteotomy, attempt to correct acetabular dysplasia by reorienting the socket into a more horizontal position to reduce contact stresses on the articular cartilage [57].
- Hip microinstability refers to femoral head micromotion within the acetabulum, which is a prolonged phenomenon that leads to cartilage damage and eventually osteoarthritis of the hip [44].
- Acetabular hip dysplasia can contribute to hip instability because of a shallow acetabular component [44].

Classification

RADIOGRAPHIC CLASSIFICATION OF DEVELOPMENTAL DYSPLASIA OF THE HIP (DDH)

- The Tönnis classification system classifies DDH displacement based on the level of the ossific nucleus relative to the lateral margin of the acetabulum [84].
- Lesser Tönnis grades of dysplasia correlate with an improved prognosis for satisfactory long-term outcomes [84].
- Each increase in the Tönnis grade at the time of diagnosis doubles the likelihood of failure of nonsurgical treatment [84].
- The Tönnis classification relies on the presence of a femoral head ossification center, which is frequently delayed in DDH [84].
- The International Hip Dysplasia Institute classification system bases the severity of subluxation on the position of the center of the metaphysis relative to the Hilgenreiner line and Perkin line [84].

- The International Hip Dysplasia Institute classification system does not require the presence of an ossific nucleus [84].
- The International Hip Dysplasia Institute classification system has been demonstrated to be reliable and prognostic for the success of closed reduction and the need for late pelvic osteotomy [84].
- In the International Hip Dysplasia Institute classification, Grade I is defined as the H-point being at or medial to the P-line [84].
- In the International Hip Dysplasia Institute classification, Grade II is defined as the H-point being lateral to the P-line and at or medial to the D-line [84].
- In the International Hip Dysplasia Institute classification, Grade III is defined as the H-point being lateral to the D-line and at or inferior to the H-line [84].
- In the International Hip Dysplasia Institute classification, Grade IV is defined as the H-point being superior to the H-line [84].
- The acetabular index is a useful radiographic measurement in children younger than 8 years [84].
- The acetabular index measures the inclination of the ossified acetabulum determined by the angle formed between the Hilgenreiner line and a line drawn from the iliac margin at the upper edge of the triradiate cartilage to the most lateral edge of the ossified acetabulum [84].
- The acetabular index progressively decreases with age but remains abnormally high in a dysplastic hip [84].

RADIOGRAPHIC MEASUREMENTS FOR ACETABULAR DYSPLASIA IN ADOLESCENTS AND YOUNG ADULTS

- In adolescents and young adults, acetabular dysplasia is most commonly measured through the lateral center-edge angle (LCEA), anterior center-edge angle, and Tönnis angle [84].
- The lateral center-edge angle of Wiberg reflects lateral acetabular coverage and is measured on the AP radiograph as the angle subtended between a vertical line and a line from the center of the femoral head to the lateral border of the sourcil [84].
- A normal lateral center-edge angle value is greater than 25° [84].
- The anterior center-edge angle reflects anterior acetabular coverage and is measured on the false-profile view as the angle formed between a vertical line and a line from the center of the femoral head to the anterior border of the sourcil [84].
- A normal anterior center-edge angle value is greater than 20° [84].
- The Tönnis angle reflects acetabular inclination and is determined from an AP radiograph as the angle formed between a horizontal line connecting the radiographic teardrops and a line connecting the medial and lateral edges of the sourcil [84].
- A normal Tönnis angle value is less than 10° [84].
- The lateral center-edge angle of Wiberg is defined as the angle between a line from the center of the femoral head perpendicular to the transverse pelvis axis and a second line from the center of the femoral head to the superolateral most point of the acetabulum [5].
- The Tönnis angle is defined by the angle of the acetabular sourcil and a line parallel to the transverse pelvis axis [5].

- Tönnis angles between 0° and 10° are considered normal [5].
- The femoral head extrusion index is defined by the length of the femoral head that lies beyond the acetabulum as a percentage of the total horizontal width of the femoral head [5].
- Femoral head extrusion index values greater than 25% are considered abnormal [5].
- Coxa profunda is diagnosed when the fossa line touches or is medial to the ilioischial line [5].

CLASSIFICATION OF OSTEONECROSIS FOLLOWING DDH TREATMENT

- The Bucholz and Ogden classification system is based on morphologic changes in the capital femoral epiphysis, the physis, and the proximal femoral metaphysis [8].
- The Bucholz and Ogden classification system is useful in determining proper treatment and prognosis for a particular patient [8].
- The proper Bucholz and Ogden classification may not be identifiable on radiographs until the child is 4 to 6 years old [8].
- The prognostic ability of the Bucholz and Ogden classification system has been questioned by an interrater reliability study which concluded that a new classification scheme is needed [8].
- A simplification of the Kalamchi and MacEwen classification scheme combines groups II, III, and IV into a single group B [8].
- Classifying osteonecrosis cases into group A or group B demonstrated that the type of reduction (closed with traction versus open without femoral shortening) was a factor in the development of osteonecrosis [8].
- The Bucholz-Ogden system is the most widely used classification system for avascular necrosis (AVN) [87].
- In Bucholz-Ogden type I AVN, changes are limited to the femoral head, and the metaphysis is not involved [87].
- Hips with Bucholz-Ogden type I AVN usually heal without significant growth disturbance, and their outcome is not compromised [87].
- The hallmark of Bucholz-Ogden type I AVN is irregular ossification of the femoral head with no abnormalities of the metaphysis [87].
- In the Kalamchi-MacEwen classification, grade 1 reflects changes confined to the ossific nucleus [87].
- In the Kalamchi-MacEwen classification, grade 2 involves the lateral growth plate [87].
- In the Kalamchi-MacEwen classification, grade 3 involves the central physis [87].
- In the Kalamchi-MacEwen classification, grade 4 indicates total physeal and head injury [87].
- Kalamchi-MacEwen grade 1 is equivalent to Bucholz-Ogden type I [87].
- Kalamchi-MacEwen grade 2 is equivalent to Bucholz-Ogden type II [87].
- Kalamchi-MacEwen grade 4 is equivalent to Bucholz-Ogden type III [87].

CLASSIFICATION OF OTHER PEDIATRIC HIP CONDITIONS

- The Delbet classification groups pediatric hip fractures according to their location: type I (transepiphyseal separations), type II (transcervical fractures), type III (cervicotrochanteric fractures), and type IV (intertrochanteric fractures) [83].
- The Delbet classification has prognostic value regarding the risk of osteonecrosis, healing rates, and malunion [83].
- The modified Waldenstrom classification system for Legg-Calvé-Perthes disease consists of four stages [86].
- The lateral pillar (Herring) classification for Legg-Calvé-Perthes disease categorizes hips into Group A (no loss of height of the lateral pillar), Group B (less than 50% loss of lateral pillar height), and Group C (more than 50% loss of lateral pillar height) [86].
- In the Herring classification, B/C border group hips are defined by a narrow lateral pillar (2 to 3 mm wide), poor ossification, or exactly 50% maintenance of lateral pillar height without central depression [86].
- The Catterall classification is used for Legg-Calvé-Perthes disease [86].
- The Stulberg Radiographic Classification of Legg-Calvé-Perthes Disease includes Class I (normal hip joint), Class II (spherical head with enlargement, short neck, or steep acetabulum), Class III (nonspherical head), Class IV (flat head), and Class V (flat head with incongruent hip joint) [86].
- At mean 40-year follow-up, 16% of Stulberg Class II hips show radiographic signs of osteoarthritis [86].
- At mean 40-year follow-up, 58% of Stulberg Class III hips show radiographic signs of osteoarthritis [86].
- At mean 40-year follow-up, 75% of Stulberg Class IV hips show radiographic signs of osteoarthritis [86].
- At mean 40-year follow-up, 78% of Stulberg Class V hips show radiographic signs of osteoarthritis [86].
- The weight-bearing or Loder classification is the most widely used system for slipped capital femoral epiphysis (SCFE) [90].
- The Loder classification defines SCFE as stable or unstable based on the patient's ability to bear weight [90].
- SCFE is classified as stable when the patient can bear weight on the involved extremity with or without crutches [90].
- SCFE is classified as unstable when the patient cannot bear weight on the involved extremity [90].
- The risk of osteonecrosis in unstable SCFE hips was reported as 47% in a single study [90].
- The risk of osteonecrosis in stable SCFE hips was reported as zero in a single study [90].
- Most cases of SCFE are stable slips, accounting for more than 90% of cases [90].
- The traditional SCFE classification based on duration of symptoms includes chronic SCFE (symptoms present for more than 3 weeks), acute SCFE (symptoms present for less than 3 weeks), and acute-on-chronic SCFE (acute exacerbation following a prodrome of at least 3 weeks) [90].
- The traditional SCFE classification has largely been replaced by the stability classification because of its better prognostic value [90].

Clinical Presentation

GENERAL PRINCIPLES AND NATURAL HISTORY

- Developmental dysplasia of the hip (DDH) represents a spectrum of disease affecting the femoral head, acetabulum, or both, ranging from physiologic immaturity to frank dislocation [3].
- The natural history of DDH includes three courses: spontaneous resolution of instability, progression to subluxation or dislocation, and subclinical instability with persistent acetabular dysplasia [12].
- In adults with long-standing dislocation, the femoral head may lie well above the acetabular margin in a thickened capsule, described as a "high-riding dislocation" [71].
- The adult dislocated femoral head is oval and flattened medially, while the acetabulum is filled with fibrous tissue, hypertrophied ligamentum teres, and thickened transverse acetabular ligament [71].
- Fully dislocated adult hips may remain free from degenerative changes for many years or the individual's lifetime [71].
- Subclinical deformities of the hip are significant predictors of radiographic osteoarthritis and joint replacement in women [7].
- Significant hip deformity resulting from childhood conditions such as DDH can lead to secondary hip osteoarthritis in adult life [2].
- Many patients previously thought to have primary osteoarthritis of the hip are now believed to have had hip impingement leading to osteoarthritis over time [2].

NEONATAL AND INFANT PRESENTATION

- In newborns, DDH may be a silent disease with subtle or no abnormalities on physical examination, as infants have no pain, evident deformity, or limitation of hip motion [72].
- Hip clicks are nonspecific physical findings in the neonatal period [14].
- Asymmetric skin folds are an unreliable and nonspecific finding for DDH diagnosis [14].
- The Ortolani test is positive when a dislocated hip is reducible, often accompanied by a palpable clunk as the femoral head reduces into the acetabulum [14].
- The Barlow test is positive when the hip on the affected side subluxates or dislocates under posterolateral force [14].
- The sensitivity of Ortolani and Barlow maneuvers may be as low as 60% [72].
- Barlow and Ortolani maneuvers may fail to predict further surgical treatment in almost two-thirds of hips [72].
- Hip instability maneuvers may become spontaneously negative within 2 to 4 weeks of life [72].
- In infants older than 6 months, common findings include asymmetric hip abduction and apparent limb shortening in unilateral dislocations [14].
- A decrease in hip abduction is the most sensitive test result for DDH [14].

- The Galeazzi test is positive when the knee on the involved side is lower than the contralateral knee, indicating unilateral subluxation or dislocation [14].
- The Galeazzi sign is demonstrated by the clinical appearance of foreshortening of the femur on the affected side [66].
- In toddlers, restricted motion may be accompanied by a limb-length discrepancy, a limp, or a waddling gait [14].
- In walking patients with dislocated hips, an obvious limping with abductor insufficiency is present, or the patient toe walks on the side of the dislocated hip [72].

ADOLESCENT AND ADULT PRESENTATION

- Adolescents may manifest fatigue and pain in the hip, thigh, or knee in addition to signs of instability or deformity [14].
- Lateral hip pain is often the initial symptom in adolescent hip dysplasia, occurring later in the day as fatigue develops due to altered biomechanics [27].
- Deep anterior groin pain generally indicates pain originating from the joint itself, such as joint overload, edge-loading, or labral injury [27].
- Deep groin pain is activity-related and improves when activity restriction is instituted [27].
- Physical examination in adolescents should include observation of ambulation for an antalgic gait or a subtle Trendelenburg gait [27].
- The impingement test assesses pain with flexion, internal rotation, and adduction to determine the likelihood of symptomatic labral pathology [27].
- Patients with late-presenting acetabular dysplasia may complain of aching pain in the groin or lateral hip that is worse with exertion and long periods of walking or standing [75].
- Physical findings in late-presenting dysplasia are usually minimal, potentially including a Trendelenburg limp, delayed Trendelenburg sign, or discomfort at the extremes of hip motion [75].
- Signs of snapping or popping may be caused by a tear in the labrum in patients with late-presenting dysplasia [75].
- Pain in late-presenting dysplasia is exacerbated when the hip is maximally flexed, internally rotated, and adducted [75].
- Radiographic dysplasia may be present without associated pain or discomfort [27].

Investigations

RADIOGRAPHY

- Conventional radiographs remain critical in the initial imaging evaluation of the hip for diagnosing conditions including developmental dysplasia of the hip (DDH), femoroacetabular impingement (FAI), and osteoarthritis [5].

- Acetabular morphology is assessed on AP pelvis radiographs to evaluate acetabular overcoverage and undercoverage [5].
- The femoral head-neck junction morphology is often assessed using the alpha angle [5].
- Some studies indicate that radiographs, particularly the Dunn 45° view, may be more accurate for determining the alpha angle measurement than CT or MRI [5].
- The AP pelvis radiograph should be performed with the lower extremities in approximately 15° of internal rotation and centered over the pelvis [5].
- Coxa profunda is diagnosed when the acetabular fossa line touches or is medial to the ilioischial line [5].
- The Tönnis angle is defined by the angle of the acetabular sourcil and a line parallel to the transverse pelvis axis, with angles between 0° and 10° considered normal [5].
- Lateral center-edge angles of 20°–40° are considered normal, while angles from 20° to 25° are considered borderline [5].
- A normal alpha angle on a Dunn 90° view is less than 50°–55°, while an abnormal alpha angle is greater than this range [5].
- The "crossover" sign on an AP pelvis radiograph indicates acetabular retroversion related to lateralization of the anterior acetabular wall relative to the posterior acetabular wall [5].
- Pelvic tilt or rotation may lead to false-positive and false-negative "crossover" signs on AP pelvis radiographs [5].
- For neutral pelvic tilt on an AP pelvis radiograph, the sacrococcygeal joint should be between 3 and 5 cm above the superior border of the symphysis pubis [5].
- Radiographic findings in the dysplastic hip include decreased lateral and anterior center-edge angles (<25° and <20° respectively), a lateralized hip center (>10 mm from ilioischial line), and an increased Tönnis angle (>10°) [80].
- Radiographically, dysplasia of the hip is characterized by an LCE angle of less than 20 degrees, with hips in the 20- to 25-degree range having borderline dysplasia [93].
- Dysplastic hips typically display an increased Tönnis angle above 10 degrees [93].
- Dysplastic hips display a lateralized hip center with a broadened radiographic teardrop [93].
- The femoral neck-shaft angle is usually increased in dysplastic hips [93].
- The proximal femur is usually excessively anteverted in dysplastic hips [93].
- The femoral head may be small and have a flattened lateral contour in dysplastic hips [93].
- Many patients with hip dysplasia display an increased alpha angle and thus have a cam morphology [93].
- Disruption of the Shenton line is present with superior and lateral positioning of the hip center and with true hip subluxation from the hip center [93].
- Important radiographic findings in pincer FAI include acetabular overcoverage, os acetabuli, and acetabular retroversion (crossover sign, ischial spine sign) [80].
- Abnormal radiographic findings in cam FAI include the anterior femoral offset (<7.2 mm), the femoral offset ratio (<0.17), and the α angle (>50°) [80].

- The AP pelvic and false-profile views reveal the most information about acetabular pathology, including version, undercoverage or overcoverage, and arthritic changes [80].
- Lateral views (frog-lateral, Dunn, cross-table) better delineate the anatomic deformities (cam lesion) of the proximal femur [80].
- An anteroposterior view with the hip slightly flexed and abducted can be performed to simulate the congruence that would be attained with a periacetabular osteotomy [93].
- The false profile is evaluated for evidence of subluxation or posterior cartilage wear in the radiographic workup of hip dysplasia [93].
- Osteoarthritis of the hip can be categorized using the Kellgren-Lawrence or Tönnis classifications [5].
- The Kellgren-Lawrence classification is a 4-point grading system classified into doubtful, mild, moderate, and severe [5].
- The Tönnis classification is a 3-point grading system categorized into mild, moderate, and severe [5].
- Radiographic and clinical severity do not necessarily correlate, particularly if the radiographs are non-weight-bearing or if false-profile views are not included [5].

MAGNETIC RESONANCE IMAGING

- MRI is the modality of choice for patients suspected of soft tissue or intra-articular pathology due to its superior sensitivity and specificity [48].
- Conventional MRI is effective at identifying osteochondral injuries, musculotendinous pathologies, and inflammation [48].
- Magnetic resonance arthrography (MRA) is more appropriate than conventional MRI to determine injuries to the labrochondral structures and the ligamentum teres and to identify loose bodies and synovial chondromatosis [48].
- The utility of MRA in the accurate detection and staging of articular cartilage lesions is reduced, with sensitivity reported to be less than 50% compared with arthroscopic findings [48].
- Recent advances in MRI imaging techniques, such as delayed gadolinium-enhanced MR imaging and T2* mapping, allow for a more in-depth analysis of the structure of articular cartilage [48].
- Delayed gadolinium-enhanced MR imaging and T2* mapping were effective at detecting early changes to the articular cartilage surfaces of patients with hip dysplasia and femoroacetabular impingement [48].
- MRI is important in the evaluation of chondral or labral pathology associated with FAI and can be performed with intra-articular contrast or without contrast if a high-level 3-Tesla protocol is used [29].
- MRI/magnetic resonance arthrography help determine the integrity of the labral and chondral surfaces and can alter surgical planning depending on the amount of degeneration [80].
- Radial and oblique axial views on MRI can accurately locate and measure the size of the cam lesion to help the surgeon preoperatively plan for femoral head/neck junction osteoplasty [80].
- An MR arthrogram is performed to evaluate the status of the articular cartilage and labrum in the radiographic workup of hip dysplasia [93].
- Noncontrast MRI at 3T is generally adequate for diagnosing intra-articular pathology [56].

- If 3T imaging is unavailable, MRA can be considered at 1.5T for increased diagnostic accuracy [56].
- A prospective study comparing asymptomatic volunteers and symptomatic patients with FAI demonstrated chondrolabral damage in 80% and 57% of patients, respectively [31].
- A prospective matched cohort demonstrated progressive degenerative changes on MRI in young athletes after five years in those with limited internal rotation in flexion (<10°) and radiographic findings of FAI [31].
- Perfusion MRI is able to predict and decrease the risk of osteonecrosis after DDH treatment by assessing femoral capital epiphysis perfusion after reduction [17].
- Hips with decreased head perfusion on postreduction MRI were revised with a new reduction and casting in a study assessing perfusion MRI [17].

COMPUTED TOMOGRAPHY

- CT scans are effective for examining cortical and cancellous bone and can be used to create three-dimensional reconstructions of the hip for use in surgical planning [48].
- Measurements of femoral head coverage and acetabular and femoral impingement can be performed reliably using CT images [48].
- CT can be useful for accurate bony measurements in symptomatic hips with dysplasia and FAI pathology [80].
- The sphericity of the femoral head can accurately be determined on CT [80].
- A clear measurement of the α angle can be performed on the sagittal-oblique image parallel to the femoral neck on CT [80].
- Cystic changes can be clearly seen within the bone, and ossification of the labrum can be better delineated on CT [80].
- CT can accurately determine version of the acetabulum and femoral version independent of patient position [80].
- Three-dimensional reconstructions on CT can help with preoperative reconstruction planning [80].
- Low-dose CT with three-dimensional reformats is particularly useful in surgical planning of complex or borderline deformities [19].
- A low-dose CT scan of the pelvis with a few slices through the epicondyles of the knee is useful to determine the pattern of acetabular dysplasia, the version of the acetabulum, and the version of the femoral neck [93].
- CT may be helpful to quantify the severity of deformity and to localize specifically areas of potential impingement as well as to measure the acetabular coverage and femoral anteversion [29].
- Three-dimensional CT with pelvic remodeling may be indicated for preoperative planning for reconstruction associated with dysplasia surgery, femoroacetabular impingement, posttraumatic arthritis, or other complex primary total hip arthroplasty [60].

ULTRASONOGRAPHY

- Ultrasonography provides real-time dynamic assessment of the hip and is useful in diagnosing soft-tissue abnormalities about the hip joint [18].
- Ultrasonography is particularly useful in providing real-time guidance during diagnostic and therapeutic procedures [18].
- Although ultrasonography is a valuable tool to examine pediatric hip conditions, its utility in evaluating the adult hip is limited [48].
- Ultrasonography can be an effective modality to identify musculotendinous disruptions, effusions associated with intra-articular pathology, or inflammatory conditions, such as bursitis [48].
- Ultrasonography is being increasingly used for targeted injections into muscles, tendons, or intra-articularly around the hip for corticosteroids or biologic treatments [48].
- The 50% rule for femoral head coverage in newborn DDH must be interpreted as a guide and not the golden rule, as other findings of residual acetabular dysplasia such as rounding of the lateral corner, notching defects, and increased echogenicity of the labrum must be considered [17].
- The ultrasonographic pubofemoral distance decreased from 6.1 mm at diagnosis to 3.0 mm at final follow-up in patients treated with the Pavlik method, while femoral head coverage increased from 30.8% to 62.1% [17].
- Males with Graf type IV hips have a greater likelihood of failure with the Pavlik method, suggesting ultrasound should be part of the initial assessment for prognostic implications [17].
- Dislocated Graf type-IV hips at diagnosis are at increased risk of residual acetabular dysplasia at 1 year after successful treatment with the Pavlik method [17].

Treatment

GENERAL PRINCIPLES AND NATURAL HISTORY

- Developmental dysplasia of the hip (DDH) represents a broad spectrum of disease affecting the femoral head, the acetabulum, or both, ranging from physiologic immaturity to frank dislocation [3].
- Large cross-sectional studies report the prevalence of hip dysplasia in the adult population is between 3% and 5% [3].
- A recent retrospective study reported that almost half of patients undergoing total hip arthroplasty before 50 years of age have osteoarthritis associated with acetabular dysplasia [3].
- Fewer than 10% of young adults requiring arthroplasty for dysplasia-associated osteoarthritis had hip instability at birth [3].
- The best results and long-term outcomes for DDH occur in patients who are treated earlier in the neonatal period with the least residual dysplasia [3].

- The goal of hip preservation surgery in dysplasia and impingement is to alter hip joint morphology to allow more unhindered physiologic range of motion while optimizing hip joint mechanics to delay or halt the progression of hip osteoarthritis [2].
- Treatment of DDH is age-related and tailored to the specific pathologic condition, with designated groups for newborn, infant, toddler, child, and adolescent/young adult [21].
- Early diagnosis and treatment are of paramount importance to favorably alter the natural history of DDH [11].
- Follow-up until skeletal maturity is warranted because the rates of adolescent and adult dysplasia have been underestimated in the past [11].

NON-OPERATIVE MANAGEMENT (INFANTS)

- Most patients in whom a diagnosis of DDH is made within 6 months of age are successfully treated with a Pavlik harness [11].
- The Pavlik harness is the first choice of treatment for children presenting between 2 and 6 months of age [53].
- To be effective, the Pavlik harness must hold the hips in more than 90 degrees of flexion, with the position of the upper femoral metaphysis pointed toward the triradiate cartilage [53].
- If reduction is not obtained within 3 to 4 weeks of Pavlik harness treatment, the harness should be discontinued and other treatment begun [53].
- If reduction is confirmed, the Pavlik harness should be continued for approximately 6 weeks after stability is established [53].
- A review of a large European series found that 95% of initially dysplastic hips were normal after Pavlik harness treatment [53].
- Eighty percent of hips that were dislocated and not initially reducible were successfully reduced with the Pavlik harness [53].
- The reported rate of avascular necrosis (AVN) when the Pavlik harness is used ranges from 0% to 15% [53].
- Factors associated with the failure of Pavlik harness treatment include patient age of more than 7 weeks at treatment, bilateral hip dislocation, and an absent Ortolani sign [53].
- Pavlik harness treatment is contraindicated in teratologic hip dislocations [62].
- In a patient with a narrow safe zone (<40 degrees), adductor tenotomy should be considered during harness management [62].
- If attempts to reduce a hip do not succeed in 3 weeks, the Pavlik harness should be discontinued to prevent erosion of the pelvis superior to the acetabulum [62].

OPERATIVE MANAGEMENT (CHILDREN AND ADOLESCENTS)

- Closed reduction is indicated for children with a dislocated hip in whom orthotic treatment has failed and for those with a late-presenting dislocated hip for whom primary Pavlik harness treatment is not suitable [10].

- Closed reduction is performed under general anesthesia with hip abduction and an anteriorly directed force on the posterior aspect of the greater trochanter to obtain reduction [10].
- The use of preoperative overhead traction has been demonstrated to offer no advantage to achieving a successful reduction or avoiding osteonecrosis in a large series of patients [10].
- Arthrography is used to evaluate the reduction intraoperatively, with a medial dye pool ≤ 6 mm or 16% of the femoral head diameter shown to be predictive of a successful reduction [10].
- Open reduction should be considered if an acceptable closed reduction is unobtainable or would require excessive force [10].
- An open reduction allows the surgeon to address impediments to reduction including the joint capsule, inverted labrum/limbus, hypertrophied ligamentum teres, pulvinar, and transverse acetabular ligament [10].
- A capsulorrhaphy can only be performed through an anterior approach during open reduction [10].
- A 2016 meta-analysis found no association between closed or open reduction before or after 12 months of age and the development of osteonecrosis [10].
- The same 2016 meta-analysis found no association between medial or anterior surgical approach and the development of osteonecrosis [10].
- In children younger than 18 months, substantial remodeling of the acetabulum can occur after a closed or open reduction without bony surgery [10].
- After 18 months of age, there is an increased likelihood of either femoral or pelvic osteotomy [10].
- A femoral shortening osteotomy may be indicated if soft-tissue contractures result in excessive pressure on the femoral head in the acetabulum following open reduction [10].
- For children aged 3 to 8 years, acetabular osteotomy is the treatment, with options including Aalter, Dega, Pemberton, or Staheli procedures [62].
- For patients older than 8 years with an open growth plate, triple (Steele), double pelvic (Southerland), or Staheli procedures are indicated [62].
- For patients older than 8 years with a closed growth plate, Ganz and Chiari procedures are indicated [62].
- Total hip arthroplasty is performed when the child is an adult [62].
- In adolescents, acetabular dysplasia is characterized by increased inclination in the coronal and sagittal planes and a lateralized hip joint center [11].
- Restoration of a normal hip joint center with improved/normalized acetabular coverage is achieved with triple innominate osteotomies in those with open triradiate cartilage or a periacetabular osteotomy in the skeletally mature patient [11].

OPERATIVE MANAGEMENT (ADULTS AND YOUNG ADULTS)

- Periacetabular osteotomy (PAO), with or without femoral osteotomy, for treatment of painful hip dysplasia in young adults appears to be effective in delaying prosthetic hip reconstruction when the surgical intervention occurs while the arthritic progression is fairly mild [2].
- The results of PAO in patients with more advanced arthritis have been less favorable [2].

- A reconstructive acetabular osteotomy is the treatment of choice for symptomatic hip dysplasia with deficient anterolateral acetabular coverage [28].
- The Bernese PAO has been popularized for acetabular reorientation and is now a mainstay of surgical treatment [28].
- The Bernese PAO is increasingly combined with hip arthroscopy in a single setting when labral pathology is present, with hip arthroscopy performed first [28].
- The Bernese PAO technique involves a modified Smith-Peterson interval, ASIS osteotomy, and ischial, pubic, iliac, and posterior column osteotomies [28].
- Acetabular reorientation during Bernese PAO is optimized under fluoroscopy before definitive fixation [28].
- Arthrotomy for head-neck junction osteoplasty is performed during Bernese PAO if there is limited range of motion or major head-neck deformity [28].
- Advantages of the Bernese PAO include a single surgical incision, preservation of blood supply to the acetabulum, maintenance of posterior column integrity, and the ability to perform a major multidimensional precise acetabular correction [28].
- Disadvantages of the Bernese PAO include anterior overcorrection (producing acetabular retroversion and associated secondary FAI), intra-articular fracture, and neurovascular injury [28].
- Reported survival for Bernese PAO is 60% at 20-year follow-up [28].
- Delayed gadolinium-enhanced MRI of cartilage (dGEMRIC) assessment of the glycosaminoglycan (GAG) content of the articular cartilage is predictive of outcome after PAO, with low GAG content associated with increased risk of failure [28].
- Femoral or periacetabular osteotomy should be considered for young patients with osteoarthritis if the joint is not grossly incongruous and satisfactory motion is present [55].
- Periacetabular osteotomy in patients with dysplasia may decrease the need for structural bone grafting if later conversion to arthroplasty is needed [55].
- If an osteotomy relieves symptoms for 10 years or more, and then an arthroplasty is required, the patient will have been able to engage in more physical activity, bone stock will have been preserved, and the patient will be older and less physically active [55].
- Before any major reconstruction of the hip is recommended, conservative measures should be advised, including weight loss, nonopioid analgesics, reasonable activity modification, low-impact exercise, and ambulatory aids [55].
- Surgery is justified if, despite conservative measures, pain at rest and pain with motion and weight bearing are severe enough to prevent the patient from working or from carrying out activities of daily living [55].
- Patients with limitation of motion, limp, or leg-length inequality with little or no hip pain are not candidates for total hip arthroplasty [55].

COMPLICATIONS AND SEQUELAE MANAGEMENT

- The most serious complication associated with treatment of DDH in early infancy is the development of osteonecrosis [8].
- Estimated rates of osteonecrosis vary widely, ranging from less than 5% to almost 50% [8].
- Proposed risk factors for osteonecrosis include open reduction with concomitant osteotomies, redislocation after surgical correction, or the need for secondary procedure after initial closed or open reduction [8].
- The rate of osteonecrosis after closed reduction is lower than after open reduction, but is still as high as 10% to 35% after closed treatment [8].
- Meta-analyses have indicated that the presence of the ossific nucleus provides little protective benefit against osteonecrosis after closed or open reduction [8].
- Delaying reduction of a dislocated hip until the appearance of the ossific nucleus more than doubled the need for future surgery [8].
- Potential sequelae of osteonecrosis include femoral head deformity, acetabular dysplasia, lateral subluxation of the femoral head, relative overgrowth of the greater trochanter, and limb-length inequalities [8].
- Osteoarthritis is a common late complication of osteonecrosis [8].
- Significantly better results have been reported in patients treated early (1 to 3 years after the ischemic insult) with innominate osteotomy than in patients treated later (5 to 10 years after the ischemic insult) [8].
- Early innominate osteotomy has been suggested to induce spherical remodeling of the femoral head, with a resultant congruous hip joint [8].
- Significant limb-length inequality can be corrected by appropriate techniques, usually a well-timed epiphysiodesis [8].
- Symptomatic overgrowth of the greater trochanter can be treated in older patients with greater trochanteric advancement, which increases the abductor muscle resting length and increases the abductor lever arm [8].

Complications

OSTEONECROSIS

- The most serious complication associated with treatment of developmental dysplasia of the hip (DDH) in early infancy is the development of osteonecrosis [8].
- Estimated rates of osteonecrosis following DDH treatment vary widely, ranging from less than 5% to almost 50% [8].
- Proposed risk factors for osteonecrosis include open reduction with concomitant osteotomies, redislocation after surgical correction, or the need for a secondary procedure after initial closed or open reduction [8].
- The rate of osteonecrosis after closed reduction is lower than after open reduction but remains as high as 10% to 35% after closed treatment [8].

- Meta-analyses indicate that the presence of the ossific nucleus provides little protective benefit against osteonecrosis after closed or open reduction [8].
- A 2016 meta-analysis found no association between medial or anterior surgical approach and the development of osteonecrosis [10].
- The proper classification of osteonecrosis may not be identifiable on radiographs until the child is 4 to 6 years old [8].

SECONDARY OSTEOARTHRITIS AND JOINT DEGENERATION

- Subtle deformity of the hip has been implicated in the development of osteoarthritis in patients previously thought to have primary osteoarthritis [2].
- Many patients formerly classified as having primary hip osteoarthritis are now believed to have had hip impingement leading to osteoarthritis over time [2].
- The prevalence of hip dysplasia in the adult population is between 3% and 5% [3].
- Almost half of patients undergoing total hip arthroplasty before 50 years of age have osteoarthritis associated with acetabular dysplasia [3].
- For a patient who recently developed Tönnis 1 degenerative change, the probability of undergoing total hip arthroplasty in 10 years based on hip morphology was approximately one in three for dysplasia of the hip [16].
- The approximate probability of undergoing total hip arthroplasty at 20 years for a patient with recent Tönnis 1 degenerative change was two in three for dysplasia of the hip [16].
- Radiographic variables with negative prognostic value for hip osteoarthritis progression include femoral head lateralization greater than 8 mm, femoral head extrusion index greater than 0.2, acetabular depth-to-width index less than 0.3, lateral center-edge angle less than 25°, and Tönnis angle greater than 8° [16].
- Asphericity of the femoral head, head-neck offset malformations, and increased femoral anteversion are often present in DDH [22].

PERIACETABULAR OSTEOTOMY (PAO) COMPLICATIONS

- Impingement adversely affects 10-year survivorship after periacetabular osteotomy for DDH [4].
- Complications associated with periacetabular osteotomy were evaluated in a prospective multicenter study [4].
- Tranexamic acid reduces blood loss and blood transfusion requirements following periacetabular osteotomy [4].
- In a series of 19 hips with symptomatic dysplasia in 14 patients with Charcot-Marie-Tooth (CMT) disease, Bernese periacetabular osteotomy complications included osteonecrosis of the femoral head, transient complete bilateral peroneal nerve palsy, inferior rami fractures, and heterotopic ossification [76].
- Complications were more frequent in patients with CMT (33%) than in those with developmental dysplasia of the hip (13%) following Bernese periacetabular osteotomy [76].

- One-third of hips after periacetabular osteotomy survive 30 years with good clinical results, no progression of arthritis, or conversion to total hip arthroplasty [4].

TOTAL HIP ARTHROPLASTY (THA) COMPLICATIONS

- Primary or conversion THA performed for developmental dysplasia adds significant complexity to the surgical procedure and risk of complications [69].
- Patients undergoing conversion THA face approximately 20% greater direct costs compared with a matched group of patients undergoing primary THA [69].
- Patients undergoing conversion THA experience significantly greater surgical times, estimated blood loss, length of stay, intraoperative complications, and postoperative complications compared to primary THA [69].
- Complications associated with total hip arthroplasty include mortality, hematoma formation, heterotopic ossification, thromboembolism, neurologic injuries, vascular injuries, limb-length discrepancy, dislocation, fractures, trochanteric nonunion, infection, and loosening [15].
- Cementless implant designs have been beset by premature and progressive failure because of inadequate initial fixation, excessive wear, and periprosthetic bone loss secondary to particle-induced osteolysis [15].
- High failure rates for metal-on-metal articulations have been caused by metal hypersensitivity reactions [15].

OTHER COMPLICATIONS

- A retrospective case-control series reported a 65% complication rate following bony hip surgery in children with cerebral palsy, with 26% of patients experiencing multiple complications [25].
- In the same series of bony hip surgery for cerebral palsy, only 15% of complications required return-to-OR and an additional 2% were life-threatening (Clavien-Dindo III-IV), with no reported perioperative deaths [25].
- Salvage surgery for late-presenting painful, debilitating hip dislocations in cerebral palsy has high complication rates, with reported rates of 24% for femoral head resection, 33.3% for valgus-producing osteotomy, 35.3% for total hip arthroplasty, and 28.6% for shoulder prosthetic interposition [25].
- The complication rate for hip arthrodesis as a salvage procedure was reported at 106.3% [25].

Recovery

LONG-TERM OUTCOMES AND SURVIVORSHIP

- Hip preservation after periacetabular osteotomy (PAO) has been achieved in 73% to 76% of patients in two mid-term studies with longer than 9-year average follow-up [30].
- Twenty-year results from the originating surgical center in Berne showed hip preservation in 60% of hips at 20-year follow-up [30].

- The 30-year survivorship of the first 75 PAOs done at the originating center has been reported as 29% [30].
- A retrospective study of patients undergoing open reduction and innominate osteotomy with mean 43-year follow-up reported hip survivorship of 99% at 30 years, but only 54% by 45 years after initial treatment [73].
- A retrospective study of closed reductions with mean 30-year follow-up reported good or excellent functional outcomes in 90% of patients, but residual radiographic dysplasia in over half of the patients [73].

PROGNOSTIC FACTORS AND RISK OF FAILURE

- Impingement adversely affects 10-year survivorship after periacetabular osteotomy for developmental dysplasia of the hip [4].
- Bilateral surgery carries a 2.9 times greater risk of needing a subsequent hip replacement than those who initially underwent unilateral surgery [73].
- The need for revision surgery is a risk factor for poor long-term outcomes following open reduction and innominate osteotomy [73].
- The approximate probability at 20 years for a patient with recent Tönnis 1 degenerative change to undergo total hip arthroplasty was two in three for dysplasia of the hip [16].
- Reduced joint space, low center-edge angle, low head to neck ratio, and osteophytes are associated with the development of osteoarthritis over an average 11-year radiographic follow-up period [16].

RESIDUAL DYSPLASIA AND SECONDARY SURGERY

- Residual dysplasia is common following closed or open reduction, as is the need for secondary surgery [11].
- Rates of secondary surgery for residual dysplasia following closed reduction have been reported between 35% and 58% [73].
- 19% of patients who underwent open reduction required secondary surgery [73].
- Continued clinical and radiographic follow-up is essential as secondary acetabular dysplasia may necessitate additional surgical intervention in adolescence or young adulthood [73].

OSTEONECROSIS AND SEQUELAE

- The most serious complication associated with treatment of developmental dysplasia of the hip in early infancy is the development of osteonecrosis [8].
- The rate of osteonecrosis after closed reduction is as high as 10% to 35% [8].
- Patients treated early with innominate osteotomy had less pain and fewer gait disturbances and required fewer additional procedures for limb-length inequality or greater trochanteric overgrowth [8].
- With later osteotomy, the femoral head was already deformed, with little potential for remodeling [8].

NATURAL HISTORY AND DISEASE PROGRESSION

- The articular damage resulting from hip impingement can occur while symptoms remain relatively mild and intermittent [2].
- The goal of hip preservation surgery in both dysplasia and impingement is to alter the hip joint morphology to allow more unhindered physiologic range of motion while optimizing hip joint mechanics to delay or halt the progression of hip osteoarthritis [2].
- Kaplan-Meier survivorship estimated that 41% of patients with no contralateral hip symptoms develop symptoms at 10 years and 19% go on to total hip arthroplasty [16].

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