Femoroacetabular Impingement

9

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Introduction

Femoroacetabular impingement (FAI) was first described by Smith-Petersen in 1936 [1], later elaborated by Ganz [2] in 2003 as "a condition of abnormal contact that may arise as a result of either abnormal morphologic features involving the proximal femur and/or acetabulum or it may occur in patients with otherwise normal or near-normal anatomic structure of the hip, who experience impingement as a result of subjecting the hip to excessive and supraphysiologic range of motion". Patients may develop hip pain and limitations in hip range of motion due to abnormalities of the proximal femur or acetabulum or due to excessive physical demands on an otherwise anatomically normal hip.

Two distinct pathomechanical types of FAI have been described: cam and pincer impingement. Cam impingement is the result of an abnormally shaped aspherical proximal femur that abuts the acetabulum. Pincer impingement is primarily caused by an acetabular abnormality resulting in pathologic contact with the femoral head-neck junction during flexion activities (Fig. 9.1). It may be seen in the setting of acetabular over-coverage (i.e. coxa profunda) or retroversion of the acetabulum and/or femur. Commonly, patients present with mixed-type impingement caused by both acetabular and femoral-sided abnormalities (i.e. cam and pincer related causes). Finally, intra-articular impingement may be seen in the setting of other hip pathologies including: slipped capital femoral epiphysis (SCFE) [3, 4], Legg-Calve-Perthes disease (LCPD) [4, 5], or post-trauma [6].

"Cam impingement is the result of an abnormally shaped aspherical proximal femur that abuts the acetabulum while pincer impingement is caused by an acetabular abnormality resulting in pathologic contact with the femoral head-neck junction".

Femoroacetabular impingement is primarily an intra-capsular phenomenon. Less common but important causes of impingement-related hip pain include those from extra-articular sources. These include those originating from the iliopsoas (i.e. coxa saltans), subspine region (i.e. prominent anterior inferior iliac spine), ischiofemoral abutment, and greater trochanter (i.e. trochanteric overgrowth with pelvic impingement). This category of pathology is referred to as extra-articular impingement. These topics, while they can be substantial sources of hip pain in adolescent patients, are beyond the scope of this chapter.

The diagnosis of FAI is complex and requires the surgeon to critically evaluate not only a patient's clinical history and physical exam, but also their imaging findings. There is a significant

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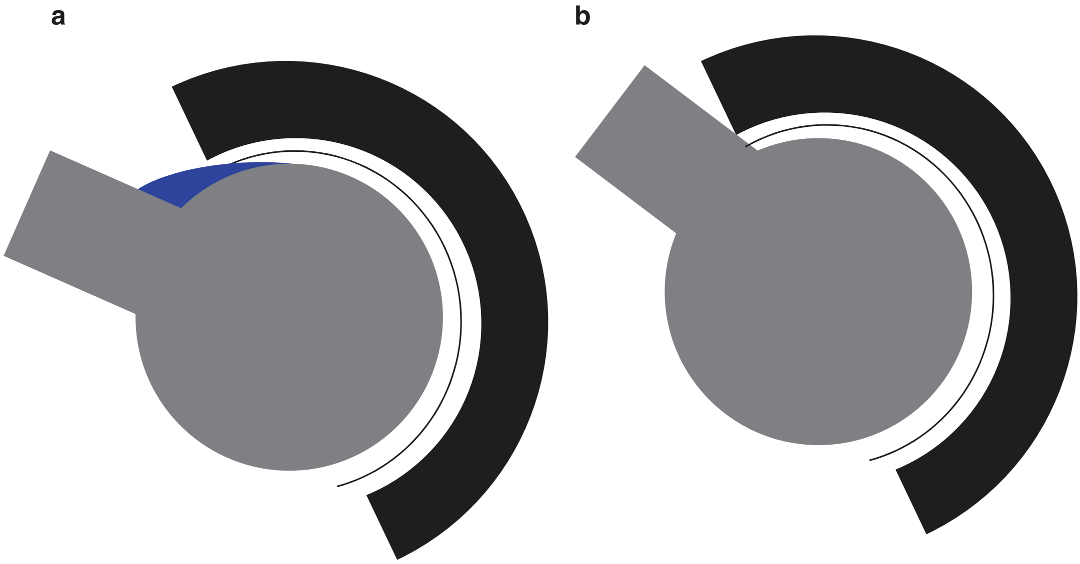

Fig. 9.1 Schematic representation of Cam and Pincer impingement. (**a**) In cam impingement, the pathologic non-spherical region of the femoral head is represented in blue, as it abuts the acetabulum. (**b**) In pincer impingement, the femoral head neck junction abuts the acetabular rim, which is typically caused by acetabular abnormalities

degree of overlap between the history and physical examination in patients with developmental hip dysplasia [7] and impingement [8, 9]. Additionally, there are a large number of asymptomatic patients whose imaging studies may demonstrate deformities often associated with FAI. It is the role of the orthopedic surgeon to correctly identify those patients with symptomatic FAI who are most likely to benefit from the appropriate non-surgical and surgical interventions.

Pathophysiology

Our understanding of the pathophysiology of femoroacetabular impingement is evolving. In the pediatric hip, impingement is often a secondary pathology, related to a prior hip disease such as SCFE [3, 4], LCPD [4, 5], or post-trauma [6]. The associated deformities and their role in impingement is beyond the scope of this chapter. The pathophysiology of FAI from primary cam and pincer deformities is less well understood.

Cam deformity may be potentially related to genetics, gender, and youth sport activity. Siblings of patients with symptomatic impingement secondary to cam deformity have a 2.8 times higher relative risk of having a cam deformity themselves [10]. Asymptomatic men have been found to have cam deformity on imaging studies more frequently than women [11].

The role of high level sports on the young patient with a developing physis is a current topic of pathophysiologic research in cam deformity development. It has been hypothesized that repetitive, supra-physiologic stresses on the developing hip cause proximal femoral remodeling resulting in cam deformity. A study of male collegiate football players identified that 95% had radiographic evidence of cam or pincer deformity [12], which is far above the prevalence seen in the general population. Additionally, cam deformity was seen at a tenfold increase in male basketball players versus age-matched volunteers who had not participated in high level sports [13]. However, it is notable that the type of sports may also have an influence, as a radiographic study demonstrated 75% of hockey players had an alpha angle (see section "Imaging") over 55°, while only 42% of skiers had abnormal values [14]. Changes within the physis in athletes with cam deformity have also been reported by the Bern group, including MRI studies with lateral extension of the capital physeal scar onto the anterosuperior femoral head when compared to control patients (Fig. 9.2) [15] and epiphyseal extension in adolescent basketball players when compared to non-athletes [16]. Finally, anatomic studies have demonstrated a unique pattern of ossification seen in some proximal femurs where a "coalesced" pattern of ossification occurs and the ossification centers of the femoral head and greater trochanter are in contact prior to epiphyseal closure [17].

"Cam deformity is thought to be caused by repetitive supra-physiologic stresses on the developing hip, resulting in an extension of the physeal scar and epiphysis".

The pathophysiology of pincer deformity is less well understood, but may also be related to genetics and gender related factors. Similar familial studies have demonstrated that siblings of patients with symptomatic impingement have a 2.0 relative risk of also having a pincer deformity [10]. There is also gender variation in pincer deformity, as it is more commonly seen in middle aged women [18]. Additionally, the radiographic findings in men and women diagnosed with pincer deformity are variable. Analysis of high-level ballet dancers demonstrated 85% of women had coxa profunda versus only 26% of men. Additionally, men were found to have a greater prevalence of prominent ischial spines and posterior wall signs than women, indicating a retroverted acetabulum [19].

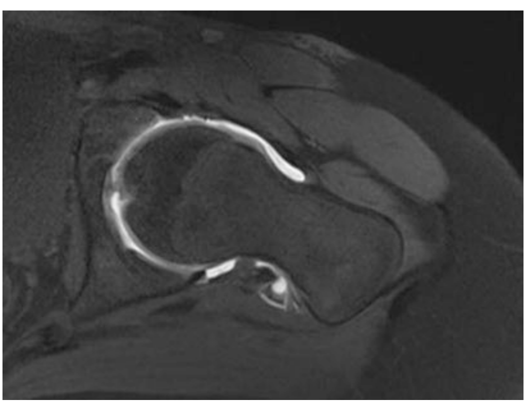

Fig. 9.2 Axial MRI of hip demonstrates lateral extension of capital physeal scar in the anterosuperior femoral head associated with a cam deformity

Natural History

The natural history of FAI is largely unknown, as the understanding has only begun to grow with the development of a safe technique for the surgical hip dislocation. Multiple studies have hypothesized the role of FAI in osteoarthritis (OA) [2, 20–22] and the potential role of surgical intervention in preventing or delaying its onset. The classic understanding of the development of osteoarthritis describes excessive contact stresses on articular cartilage due to a reduced joint contact area, as is seen in patients with developmental hip dysplasia (DDH) or following trauma. For the majority of patients with "primary" osteoarthritis, no such mechanisms are typically identified as being causative. Recently, it has been hypothesized that, in these patients, varying degrees of impingement may be responsible [18]. Surgical hip dislocation has allowed for further study of the wear patterns in FAI patients, with cam deformity typically being associated with antero-superior and central OA and pincer deformity resulting in more peripheral OA [23]. However, other studies have shown less convincing evidence of the role of FAI in progression of OA. A radiographic study of patients undergoing total hip arthroplasty evaluated the contralateral hip and found that once a patient developed radiographic evidence of arthritis (Tönnis 1), the rate of progression was significantly faster in patients with DDH than FAI or morphologically normal hips. The probability of undergoing THA was 1 in 3 for patients with DDH and 1 in 5 both for patients with FAI and for those with morphologically normal hips at 10-year follow-up. Similarly, at 20 year follow-up it was found that in patients with DDH the probability of THA was accelerated at a rate of 2 in 3. However, in patients with FAI and morphologically normal hips the probability of undergoing a THA was only 1 in 2 [24].

Radiographic studies have demonstrated an accelerated development of osteoarthritis in patients with cam deformity, but have had mixed outcomes with pincer deformity. A prospective cohort study followed both patients with acetabular dysplasia (lateral center-edge angle (LCEA) less than 20°) and pincer deformities (LCEA greater than 40°) at 5 year follow-up to determine their association with the development of OA. They found that 7% of patients with dysplasia developed incident OA but no such association was found with pincer deformities. Indeed, pincer deformity was found to be protective when an increased CEA was seen on both anteroposterior (AP) and false profile views [25]. A similar cohort study demonstrated an odds ratio of 3.67 and 9.66 for moderate (alpha angle greater than 60°) and severe (alpha angle greater than 83°) cam deformity for development of end-stage OA at 5 year follow-up, respectively [26].

Interestingly, there have been multiple studies published which demonstrate the prevalence of asymptomatic FAI [27]. The prevalence of radiographic cam deformity has been reported to be between 24 to 30% for asymptomatic males [11, 28] and 11% in asymptomatic women [11]. In asymptomatic adolescent patients, a prevalence of 17% for cam deformity and 32% for pincer deformity [29] has been reported. This further complicates our understanding of the natural history and further research is needed to elucidate which hips are at highest risk for degeneration, why degeneration occurs and which hips may benefit from surgical intervention.

Epidemiology

The prevalence of primary FAI varies depending upon age, gender, athletic status, and clinical symptoms. A 2015 systematic review evaluating all populations found the prevalence of asymptomatic cam deformity to be between 37 to 54.8% in athletes versus 23.1% in the general population. The prevalence of pincer deformity in asymptomatic patients was 67% [30].

In asymptomatic young (age less than 30 years) patients the prevalence of cam deformity has been reported between 24 to 29% in men [28] and 5.4% in women [27]. In a randomly selected pool of female collegiate athletes, the incidence of deformity is higher with a radiographically identified cam lesion found in 48% and pincer lesion in 1% [31].

In symptomatic patients, the prevalence of deformity is higher. In young patients presenting for evaluation of hip pain, 87% had at least one radiographic sign of FAI including a herniation pit, pistol grip deformity, crossover sign, elevated center-edge angle, and/or elevated alpha angle [32]. In an older age group (mean age 50.4 years old), 42.6% had radiographic evidence of either femoral or acetabular impingement [33]. In patients scheduled for total hip replacement (mean age 62 years-old), 44% of men and 35% of women had radiographic evidence of cam deformity [34].

Clinical Presentation

The diagnosis of femoroacetabular impingement is made after considering a patient's clinical history, physical exam, and imaging findings. Although all patients describe hip pain, the characteristics of the pain are variable. In 2009, Clohisy described the variation in hip symptoms attributed to FAI, reporting that 65% of patients described pain of insidious onset, 21% had antecedent trauma, and 14% described an associated acute injury. The pain was sharp in 73%, achy in 73%, and burning in 25%. The pain may be associated with mechanical symptoms such as catching, and typically has multiple aggravating factors including activity, running, sitting, pivoting, walking, and prolonged standing. The location is also variable with 88% of patients describing groin pain, but 67% with lateral hip pain, 35% with anterior thigh pain, 29% with buttock pain, 27% with knee pain, and 23% with low back pain [8].

"The diagnosis of femoroacetabular impingement is made after considering a patient's clinical history, physical exam, and imaging findings. While it is important

to note that that the clinical presentation can mimic DDH, keep in mind the two mechanical conditions are not mutually exclusive".

It is also important to note that the location of pain, as well as the associated aggravating factors, are very similar to the clinical presentation of DDH [7, 8]. It can be very challenging to distinguish between the two and some patients may actually have a mixed picture, as the mechanical disorders are not mutually exclusive. It is recommended that the surgeon use a combination of imaging, physical exam, and history to guide their management, as clinical history alone is not sufficient to distinguish between these two hip pathologies [9].

Physical examination of a patient with suspected impingement should include all components of a standard hip examination including gait evaluation, palpation, range of motion, muscle strength testing, and relevant special tests. Gait analysis of patients with unilateral cam deformity demonstrates decreased range of motion in both the frontal (decreased hip abduction) and sagittal planes during gait when compared to controls [35, 36]. Normative data demonstrates that, in asymptomatic young male patients, passive impingement-free range of motion is approximately 95 degrees of flexion [37]. By contrast, hip range of motion in patients with impingement is often characterized by painful and limited hip flexion by 15–21% when compared to matched controls [38].

"The physical exam of patients with hip impingement often demonstrates painful and limited hip ROM, particularly in flexion and internal rotation".

Assessment of internal and external rotation are also important indications of femoral and acetabular version, which may contribute to impingement. The prone trochanteric test can be useful as a reliable means to estimate femoral anteversion. Evaluation of peri-articular muscle strength, including the tensor fascia lata, quadriceps and abductors (including the Trendelenberg sign), provides valuable information. Finally, special tests should be performed, including the anterior impingement test and posterior impingement test. The anterior impingement test, first described by Ganz in 2003, is performed with the patient in a supine position, the hip is rotated internally, as it is passively flexed to 90° and adducted (Fig. 9.3) [2]. This exam maneuver brings the femoral neck and acetabular rim in contact and may cause pain when there is intra-articular pathology. The posterior impingement sign is performed with the patient supine with legs hanging free off the bed in extension. With increased extension and external rotation, deep-seated posterior pain will occur in patients with posterior impingement [2]. Other special tests may be considered including the Stitchfield (resisted straight leg), FABER, or dynamic range of motion to identify regions of impingement including abduction/adduction with internal and external rotation of the femur.

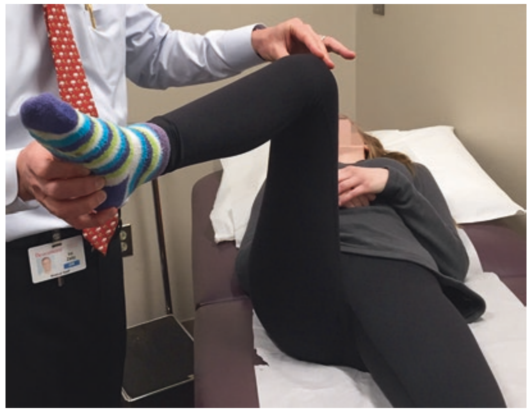

Fig. 9.3 Image demonstrates the anterior impingement test. The patient is placed in a supine position and the hip is rotated internally, as it is passively flexed to 90° and adducted

Essential Clinical Tests

1. Gait assessment looking for asymmetry
2. Trendelenburg sign
3. Range of motion (especially flexion and internal rotation)
4. Trochanteric test to estimate femoral anteversion
5. Impingement tests (anterior and posterior)

Imaging

Thorough assessment of femoroacetabular impingement often requires the use of multiple imaging modalities including plain X-ray films, computerized tomography (CT) scan, magnetic resonance imaging (MRI) and MR arthrogram.

Initial evaluation should begin with plain film X-rays, which should include anteroposterior pelvis (AP), Dunn, cross-table or frog leg lateral, and false profile views. These radiographs allow for the surgeon to obtain a general sense of the proximal femoral and acetabular morphology. Generally, the AP and false profile provide more information about the acetabulum and the lateral and Dunn views demonstrate the morphology of the proximal femur.

"Initial evaluation should begin with plain film X-rays, which should include anteroposterior pelvis (AP), Dunn, cross-table or frog leg lateral, and false profile views".

The first step to appropriately evaluate patients with hip pathology is to obtain high quality radiographs. Beginning with the AP pelvis X-ray, the patient should be positioned supine with both legs internally rotated 15° and X-ray beam centered between the pubic symphysis and the anterior superior iliac spines (ASIS). The Dunn, cross-table and frog leg views all provide lateral views of the hip. The Dunn lateral is performed with a patient supine and the symptomatic hip abducted 20° and flexed to 45° or 90° with the X-ray beam pointed between the ASIS and pubic symphysis. The cross table lateral is performed with a patient supine and the contralateral hip and knee flexed to greater than 80° with the symptomatic hip internally rotated 15°. The X-ray beam is placed parallel to the table and oriented 45° to the symptomatic hip and centered on the femoral head. A frog leg lateral view is obtained by placing the patient supine and flexing the knee 30° with the hip abducted 45° and the foot resting against the medial contralateral knee. The X-ray beam is centered midway between the ASIS and the pubic symphysis. The false profile view is obtained with the patient standing with the symptomatic hip against the cassette and the pelvis rotated 65° with the X-ray beam centered on the femoral head [39].

Beginning with the AP pelvis X-ray the surgeon should assess for congruency and sphericity of the femoral head. Cam (i.e. pistol grip) deformity and herniation pits may be identified. Herniation pits, first described in 1982 by Pitt [40] are fibrocystic lesions found at the anterosuperior head neck junction that form secondary to invagination of the synovium through cortical defects in the proximal femur. Initially described as an incidental findings, multiple papers have now demonstrated that they may or may not be associated with FAI [41, 42, 43]. Beyond these obvious radiographic findings of impingement, it is important for the surgeon to assess the version of the acetabulum. The AP film should be assessed for the presence of a crossover sign, ischial spine sign, and posterior wall sign, which may indicate retroversion. To identify a "crossover sign", lines marking the edge of the anterior wall and posterior wall of the acetabulum should be identified. If these cross over each other, this is termed a *crossover sign* and may be a marker of acetabular retroversion. However, it is important to note that it has been shown that the crossover sign can be seen in patients without acetabular retroversion due to variable anterior inferior iliac spine morphology [44]. Another important radiographic marker of retroversion is the *ischial spine sign*, where the ischial spine is visible within the pelvic brim [45]. Finally, the *posterior wall sign* is considered to be positive (retroverted) when the posterior wall of the acetabulum is found medial to the center of the head. Due to morphological differences in the acetabulum and pelvis, as well as positional changes in pelvic tilt and rotation, acetabular retroversion is most accurately diagnosed in patients that display multiple of these radiographic abnormalities, rather than one isolated finding [46].

It is also important to assess for acetabular depth and presence of protrusio. To identify protrusio the ilioischial line should be identified and the position of the hip relative to this line is assessed. Hips are termed coxa profunda if the floor of fossa acetabuli is medial to the ilioischial line and protrusio acetabuli if the medial aspect

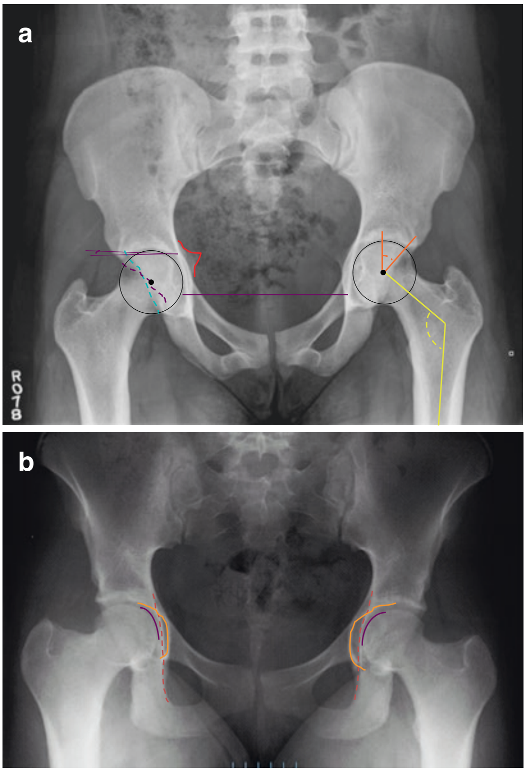

Fig. 9.4 AP pelvis X-ray illustrates common radiographic measurements (**a**) the center of the femoral head is identified with a small black dot. Common angles including the lateral center edge angle (orange), femoral head-neck offset (yellow), and Tönnis angle (purple) are identified. To assess for retroversion, the posterior wall (dashed blue line) and anterior wall (dashed purple) are identified. This X-ray demonstrates a positive crossover sign, with the anterior wall and posterior wall crossing each other. A positive ischial spine sign is demonstrated in red. The posterior wall sign is negative in this X-ray, as the center of the femoral head is located medial to the posterior wall (dashed blue line). Coxa Profunda (**b**) is demonstrated by the floor of the acetabulum (orange line) located medial to the ilioischial line (dashed red line). The femoral head is outlined in purple. In this X-ray, the patient does not have protrusio acetabula, as the head remains lateral to the ilioischial line

of the head is medial to this line. Finally, the surgeon should also measure the lateral center-edge angle of Wiberg, Tönnis angle, and the head-neck offset (Fig. 9.4).

Additional X-ray views may be used to further assess congruency, joint space narrowing, joint morphology, and head neck offset. Lateral views, such as Dunn, cross table (Fig. 9.5) or frog leg, provide an alternative view to evaluate for herniation pits. The Dunn lateral view is used specifically to measure the alpha angle of Nötzli. The alpha angle is measured by drawing a line down the center of the femoral neck and a second line from the center of the femoral head to the point where the distance from the center of the head exceeds the radius of the femoral head [47]. Finally, the anterior center-edge angle or angle of Lequesne is measured on the false profile view, this measurement assesses the degree of anterior coverage of the femoral head. Congruence and the presence of degenerative arthritis is best identified on the false-profile radiograph where joint space narrowing is more easily diagnosed than on an AP view (Fig. 9.6).

Additional imaging may be considered in patients with suspected FAI. Computerized tomography (CT) scan can provide a true assessment of acetabular version to avoid potential false positives for acetabular retroversion on plain films. It has been shown, for example, that an anteverted acetabulum can be associated with a crossover sign (typically associated with acetabular retroversion) on plain film when a prominent anterior inferior iliac spine is present [44].

Magnetic Resonance Imaging (MRI) and MR-arthrography provide a much clearer view of intra-articular structures. The addition of intra-articular contrast helps to delineate labral tears as well as chondral injury to the acetabulum and proximal femur. A prospective imaging study demonstrated increased sensitivity for identifying labral pathology (61–80% vs. 50%) and acetabular defects (71–92% vs. 58–83%) when MR arthrography was compared to standard MRI, while there was found to be no difference for femoral-sided cartilage damage [48]. A later study in 2018 demonstrated similar rates of sensitivity of 3T standard MRI vs. 1.5T arthrogram for the diagnosis of cartilage delamination and labral tears, and in fact the standard MRI showed a higher sensitivity for identifying acetabular cartilage damage [49]. The intra-articular damage pattern associated with FAI may vary depending upon whether the pathologic mechanism is primarily cam or pincer. In patients with cam impingement, there is an often a detachment of

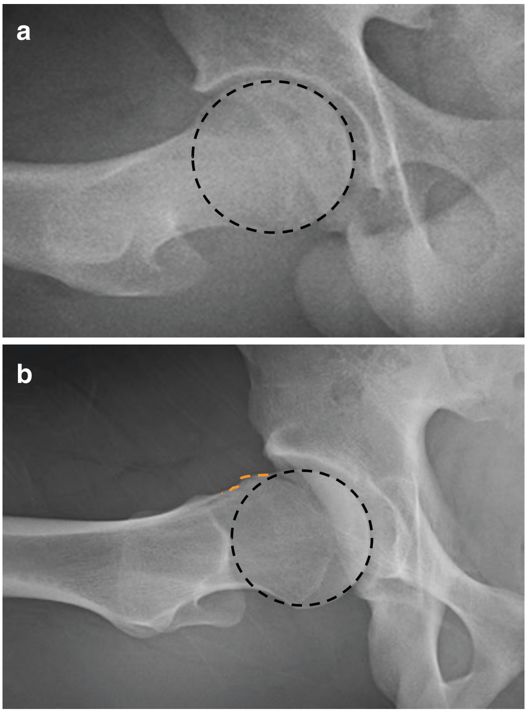

Fig. 9.5 Cross table lateral X-ray illustrates (**a**) normal femoral head-neck junction and (**b**) abnormal cam deformity in the anterior-superior femoral head neck junction (dashed orange line)

Fig. 9.6 AP pelvis demonstrates joint space narrowing and incongruence of the hip joint associated with cam deformity

the labrum from the rim of the acetabulum with a distinct space between the labral damage and a partial or full thickness delamination of the cartilage within the anterior-superior joint (Fig. 9.7).

Fig. 9.7 Coronal MRI of hip demonstrates superior labral detachment from acetabular rim secondary to cam impingement

In pincer impingement, the damage is often more peripheral, with a trough found in the femoral neck and peripheral acetabular cartilage damage where the labrum is crushed (Fig. 9.8c). There may also be a "contre-coup" injury in the posterior-inferior acetabulum, caused by the anterior levering of the femur [50–54].

Delayed Gadolinium enhanced MRI of cartilage (dGEMRIC) has recently been utilized to attempt to identify cartilage injury at earlier stages than standard MR imaging. dGEMRIC is performed by giving patients IV gadolinium contrast and allowing patients to exercise on a treadmill for 15 min while the gadolinium diffuses into cartilage in the hip joint. The negatively charged contrast agent is attracted to Glycosaminoglycans (GAGs) found in healthy cartilage. These GAGs begin to degrade over time as cartilage damage occurs. MR images are obtained and the T1 sequences are then further evaluated for degree of enhancement [55]. As this time, dGEMRIC is a relative new technology and research is still ongoing to determine its utility and thresholds for normal and abnormal cartilage enhancement. Lattanzi in 2014 published a proposed threshold of $z \leq -2$ standard deviation from a patient's normal T1 cartilage to identify lesions. With this threshold, they found

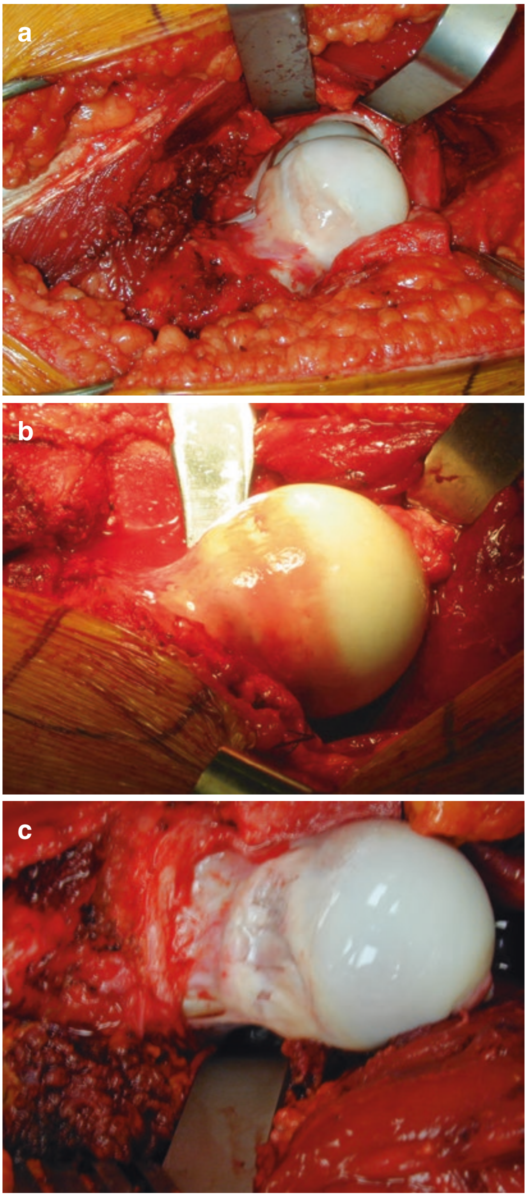

Fig. 9.8 Intra-operative images during surgical hip dislocation demonstrating (**a**) the degree of exposure of both acetabulum and proximal femur, (**b**) cam deformity and (**c**) pincer deformity (with a trough evident in the femoral neck)

a sensitivity of 88% and specificity of 51% in a retrospective review of 20 patients [56]. Additionally, studies have shown significant variability in the degree of correlation between dGEMRIC imaging and intra-operative findings, from poor [57] to moderate to strong [58] illustrating the need for further research on this topic.

Standard MR imaging utilizes orthogonal views including sagittal, coronal, and axial planes. Due to the spherical nature of the hip, the classic orthogonal views provide incomplete imaging of the articular cartilage and can make diagnosis of labral pathology particularly challenging. Radial MRI can be performed centered on the acetabulum with radial cuts, allowing for a more complete view of the labrum. Research-to-date has demonstrated utility of radial MRI for patients with dysplasia, both in classifying labral morphology [59] and in helping to identify early arthritic changes better than plain film [60]. There is minimal data to date on the role of radial MR in patients with hip impingement, although the imaging technique will likely become more relevant in the future.

Essential Imaging Test and Measurements

1. Radiographs: Femoral/acetabular morphology, offset, depth, congruence, alpha angle, center edge angle, crossover sign, and posterior wall sign
2. CT: for assessment of acetabular and femoral version
3. MRI: for assessment of labrum and articular cartilage damage

Non-operative Management

The goal of non-operative management of FAI is primarily pain reduction. Conservative management may result in significant improvement in symptoms for patients, however it is important that patients understand that it will not result in an improved range of motion.

"Conservative management may result in significant improvement in symptoms for patients, however it is important that patients understand that it will not result in an improved range of motion".

Mainstays of non-operative treatment include non-steroidal anti-inflammatory medications (NSAIDs), physical therapy, injections, and rest/activity modification to avoid provocative activities. In patients with mild FAI, 89% of patients saw improvement in Harris hip scores after adopting a safe range of motion and modifying activities of daily living to avoid provocative positions [61]. Intra-articular injections may also be considered in FAI, with both hyaluronic acid [62] and corticosteroid injections [63, 64], showing temporary improvement in pain scores. Physical therapy protocols should focus on strengthening of muscles surrounding the hip joint, muscle activation, and neuromuscular re-training, rather than range of motion, which is likely to further exacerbate symptoms [65]. Finally, it is important that patients who are managed non-operatively be followed at regular intervals as the options for hip preservation surgery may become limited if a patient's disease progresses to involve significant intra-articular damage.

Essentials of Non-operative Management

1. Non-steroidal anti-inflammatory medications
2. Physical therapy emphasizing peri-articular muscle strengthening and re-training
3. Corticosteroid injections

Non-operative Pitfalls

1. Important to mitigate patient's expectations, with the goal to improve pain, but not range of motion
2. Important to continue to follow patients regularly since if the disease progresses to involve significant articular damage, the options for surgical intervention become limited

Operative Management

Operative indications for FAI are continuing to evolve and include a combination of patient symptoms, physical exam findings, and imaging abnormalities. A recent systematic review identified current operative indications for open surgical hip dislocation for FAI [66]. These indications included: hip or groin pain for a minimum of 3 months to 1 year that impacts activities of daily living and worsens with flexion activities, failure of non-operative management for a minimum of 1–3 months, mechanical symptoms, positive impingement sign and limitation in hip range of motion on physical exam, and radiographic or MRI abnormalities. Specific indications for both open and arthroscopic intervention for FAI in skeletally immature patients are similar and include: (1) clinical history of anterior groin pain unresponsive to conservative management, (2) decreased hip ROM and positive impingement sign, (3) radiographic findings such as decreased offset, increased alpha angle, and labral tears, and a positive response to intra-articular injections. The most significant contraindication is significant degenerative changes within the hip joint [67].

When planning surgical treatment of FAI, it is crucial for the surgeon to confirm the diagnosis of FAI and to identify the anatomic structures that may be the source of impingement. Potential pathologies that may need to be addressed include labral injury, articular cartilage damage and bony deformity. Surgeons must consider the need for labral repair or debridement, osteochondroplasty of the femur or acetabulum, as well as femoral head and neck, acetabular and trochanteric osteotomies. Based upon the degree of pathology and the anticipated procedures that must be performed, the optimal surgical approach/technique can be determined.

"When planning surgical treatment of FAI, it is crucial for the surgeon to identify the anatomic structures that may be the source of impingement. Based upon the degree of pathology and the anticipated procedures that must be performed, the optimal surgical approach/technique can be determined".

Surgical options include open surgical dislocation, arthroscopy, and less commonly, periacetabular osteotomy and femoral derotational osteotomy. Historically, an anterior mini-arthrotomy, with or without arthroscopic assistance, was used to address the anterolateral femoral head-neck junction and anterior acetabular pathology. This technique is still supported by some authors [68].

Open Surgical Hip Dislocation

The open surgical hip dislocation, first described by Ganz in 2001, utilizes the Gibson approach to access the hip and may be used to treat both cam and pincer deformity [69]. Through the use of the trochanteric slide osteotomy, the short external rotator muscular attachments are preserved, protecting the primary blood supply to the femoral head, the medial femoral circumflex artery.

> ***"Through the use of the trochanteric slide osteotomy, the short external rotator muscular attachments are preserved, protecting the primary blood supply to the femoral head, the medial femoral circumflex artery".***

Once an anterior capsulotomy and dislocation is performed, the surgeon has access to all potential intra- and extra-articular sources of impingement as well as the ability to dynamically examine the hip prior to and following anatomic modifications. The greatest benefit is that this approach provides tremendous versatility allowing the surgeon to perform labral debridement, femoral and acetabular osteochondroplasty, relative neck lengthening or osteotomies, and trimming and transplantation of the trochanters (Fig. 9.8). If the dissection is continued to include an extended retinacular flap [70], the surgeon may also address complex deformities of the femoral head, such as seen with residual Legg-Calve-Perthes. The use of an open surgical hip dislocation also avoids the risk of traction, fluid extravasation, or capsular disruption, common sources of complications following arthroscopic surgery. The potential risks of surgical dislocation are often attributed to the greater trochanteric osteotomy and include residual pain, delayed union and nonunion. Post-operatively, patients often require a minimum overnight hospitalization following dislocation, while arthroscopy can often be performed as an outpatient procedure. Additional, rare complications include heterotopic ossification, infection, and deep vein thrombosis [71, 72]. Finally, the most feared complication of this approach is avascular necrosis of the femoral head. In the hands of an experienced surgeon, the incidence of this complication is nil [69]. It is of paramount importance that the surgeon understand the anatomy of the blood supply to the femoral head and retinacular vessels prior to attempting this technique (Chap. 2).

Surgical Technique: Open Surgical Hip Dislocation (Bern Technique)

- A Gibson approach to the hip is performed. The patient is placed in the lateral decubitus position with the hip flexed to approximately 40° and the leg elevated on a 'tunnel pillow' (one with an arched cutout on its inferior aspect to accommodate the contralateral leg) or blanket rolls if unavailable. The surgical incision is centered on the greater trochanter with equal limbs proximally and distally. The subcutaneous tissue is divided with electrocautery to the fascia lata and gluteus fascia. The iliotibial band is incised from distal to proximal, starting a little posterior to the center of the femoral shaft and stopping at the inferior level of the greater trochanter at the level of insertion of the gluteus maximus tendon. The hip is then extended, and the knee is flexed to open up interval between gluteus maximus and gluteus medius. The muscle fibers of gluteus maximus are identified "from inside out" and the proximal incision of the iliotibial band is made just anterior to these fibers. The trochanteric bursa is incised in line with the incision, allowing for later re-approximation during wound closure.
- The vastus lateralis muscle is then dissected from the lateral intramuscular septum, with extraperiosteal dissection of the femur antero-

laterally to allow for subsequent ease of mobilization of the greater trochanteric osteotomy. An incision is then made at the posterior most fibers (about 5 mm) of the gluteus medius, leaving these fibers attached to the "stable trochanter" (i.e. non-mobile fragment). It is important to preserve the posterior superior tendinous attachment of the gluteus medius to the stable trochanter. Electrocautery is then used to prepare the osteotomy site of the greater trochanter, extending from this point to the point at which the vastus lateralis edge meets the greater trochanter posteriorly.

- Either a flat osteotomy or a "step cut" of the greater trochanter is performed depending on the surgical indication. If distalization of the greater trochanter is planned, a flat osteotomy is required. If no distalization is needed, the step cut is thought to improve trochanteric stability and healing rates. The step cut technique is as follows: a straight cut is made from the proximal half of the greater trochanter; a free sawblade is then placed in this osteotomy site as a parallel reference for the distal (oblique) osteotomy. The oblique cut is angled medially from distal to proximal, meeting at the halfway point. A small 1/4″ osteotome is then used to connect the two osteotomies with a vertical cut. For each half osteotomy and vertical cut, these are made from anterior to posterior to approximately 80% of the width of the greater trochanter (i.e. incomplete). Two broad osteotomes are then placed at each half osteotomy and used as levers to complete the trochanteric osteotomy. The resulting anterior "crack" results in the formation of a bony ledge which is meant to further confer more stability. It is important to preserve the posterior superior tendinous attachment of the gluteus medius to the stable trochanter.
- A right angle clamp is passed medial to the gluteus medius tendon which is then carefully transected. The vastus lateralis fibers are dissected extra-periosteally from the anterior femur and the hip is flexed and slightly externally rotated to identify the interval between the gluteus minimus and the piriformis. The gluteus minimus muscle is gently dissected from the superior hip capsule until the iliocapsularis is identified. The vastus lateralis is dissected from the anterior hip capsule until the capsule was exposed from the piriformis posteriorly to the reflected head of the rectus femoris proximally to the rectus muscle inferiorly. A Hohmann retractor placed under the mobile trochanter fragment may assist with exposure over the anterior capsule. From this point, it is important to stay superior to the piriformis tendon at all times to protect the medial femoral circumflex artery (MFCA) (see Chap. 2 for MFCA anatomy).
- Alternatively, the gluteus minimus dissection may be started prior to the osteotomy to facilitate completion of the capsular exposure. The gluteus medius is retracted to reveal the underlying gluteus minimus draped over the anterolateral hip capsule. The gluteus minimus muscle is then dissected off the capsule for as much as possible, prior to performing the osteotomy.
- A Z shaped capsulotomy is performed dividing the capsule along the anterolateral femoral neck towards the base of the trochanter, inferiorly from the base of the trochanter towards the base of the acetabulum diverging slightly from the intertrochanteric line, and posteriorly parallel to the acetabular labrum continuing along the ischium anterior to the piriformis muscle. The hip joint is now exposed.
- The femoral neck is then inspected to look for proximal femoral abnormalities such as a cam lesion (Fig. 9.8b). The hip is then taken through a range of motion (in particular, flexion and internal rotation) to look for areas of impingement.
- The retinacular vessels are then identified at their point of epiphyseal perforation, at the 11 o'clock position on the femoral head. Their position acknowledged, a large bone hook is then placed around the anteromedial femoral neck and an upward force is applied with the hip in some traction and external rotation. A curved Mayo scissors is then used to release the ligamentum teres, allowing for dislocation. The hip is then carefully externally rotated, and the leg is placed in a sterile bag in a vertical position as is standard for total hip replacement procedures.

- At this point, both the femoral head and the acetabulum can be fully inspected, assessing for cartilage lesions and labral detachment which may either be debrided or repaired depending on their severity. In addition, for pincer or combined lesions, the labrum can be sharply detached from the bone, exposing the overhanging anterior acetabular rim which can then be "trimmed" to eliminate the source of impingement. The labrum is then reattached to the remaining rim using suture anchors.
- If a substantial cam lesion is present, a curved osteotome is then used to start the cam resection in a proximal to distal fashion, starting at the junction of the articular cartilage and femoral neck (i.e. femoral osteochondroplasty). The bone is removed to create a normal offset. The retinacular vessels are identified and protected throughout this procedure. A motorized burr is used to finesse the reshaping of the femoral neck and restoration of femoral offset. If need be, an extended subperiosteal retinacular flap can be developed to safely resect impinging bone near the perforation of the retinacular vessels into the femoral head [73].
- After addressing all aspects of the intra-articular pathology, the wound is irrigated and capsule repaired. The trochanteric osteotomy approximated (and distalized as appropriate). The osteotomy is fixed with two 3.5 mm fully threaded cortical screws, aiming in the direction of the lesser trochanter. The gluteus medius tendon is repaired with a figure-of-8 stitch and the vastus lateralis fascia with a running suture. The trochanteric bursa sleeve is typically repaired to protect against screw irritation. The wound is then closed in layers.
- Post-operatively, the patient is touch-toe weight-bearing for 6 weeks with active abduction discouraged. Typically, patients return to active sport by three months postoperatively.

For further information regarding the surgical hip dislocation technique, please see Ganz' classic paper [69]. Further information regarding more complex techniques including relative neck lengthening and femoral head reduction osteotomy are beyond the scope of this chapter but may be found in the paper published by Ganz and Leunig in 2011 [73].

Hip Arthroscopy

For the appropriate surgical candidate, hip arthroscopy is a less-invasive technique to approach both cam and pincer pathomorphology that can cause FAI. While data is limited in the adolescent population, hip arthroscopy has been shown to be safe and have similar rates of effectiveness as arthroscopy for adults in treating FAI [74]. Arthroscopy allows for labral repair and debridement, acetabular rim trimming, as well as femoral osteochondroplasty. Arthroscopy requires minimal surgical dissection and does not include trochanteric osteotomy, eliminating the risk of nonunion or chronic pain. It can often be done as an outpatient procedure with a local nerve block. The greatest difficulty with the use of arthroscopy for FAI is somewhat limited visualization and joint access. Furthermore, advanced arthroscopic skills and experience are required to treat all associated pathology. Access to the posterolateral femoral neck is very difficult with an arthroscope and techniques such as relative neck lengthening requiring retinacular flaps, femoral osteotomies or translation of the trochanter are not possible.

> ***"Access to the posterolateral femoral neck is very difficult with an arthroscope and techniques such as relative neck lengthening requiring retinacular flaps, femoral osteotomies or translation of the trochanter are not possible".***

Other complications associated with arthroscopy include iatrogenic chondral and labral damage, traction injuries (including temporary or permanent nerve injury and perineal skin damage), infection, deep vein thrombosis, heterotrophic ossification, and extra-articular fluid extravasation [75]. Finally, there is a potential risk for iatrogenic destabilization of the hip, with many surgeons now performing arthroscopic closure of the capsule [76]. Hip arthroscopy in an adolescent population contains several unique theoretical risks, including iatrogenic slipped capital femoral epiphysis, proximal femoral growth disturbance, and avascular necrosis of the femoral head, although these have not been identified to date in the current literature. A 2011 review demonstrated complications rates similar to adults (1.8%) and included transient nerve palsy, suture abscess, and instrument breakage [77].

In specific patient populations, additional surgical procedures may be considered to treat hip impingement including reverse (anteverting) periacetabular osteotomy and femoral derotational osteotomy. In patients with significant acetabular retroversion and posterior under coverage, an anteverting periacetabular osteotomy with possible femoral neck osteoplasty could be considered [78]. For patients with impingement secondary to significant femoral retroversion, surgeons may consider a derotational femoral osteotomy. Overall, the most important aspect of surgical intervention is an understanding of the complex range of deformity that may result in impingement and choosing the correct approach to address a patient's pathology.

Essential Surgical Techniques

1. Open surgical hip dislocation
2. Extended retinacular flap and relative femoral neck lengthening (most commonly used for LCPD)
3. Arthroscopic femoral osteochondroplasty and labral repair

Operative Pitfalls

1. Identify the pathology pre-operatively to ensure that you can access everything that needs to be addressed with the approach you choose
2. Use great care to prevent avascular necrosis of the femoral head by avoiding disruption of the posterosuperior ascending vascular supply with the open surgical dislocation technique
3. Use great care to prevent growth arrest of the proximal femur by avoiding violation of the perichondrial ring with the open surgical dislocation technique in skeletally immature patients
4. Avoid iatrogenic destabilization of the hip by performing arthroscopic closure of the capsule when using arthroscopy
5. Avoid temporary or permanent nerve and perineal soft tissue traction injuries by using a well-padded post and avoiding prolonged traction times with hip arthroscopy

Classic Papers

Ganz R, Parvizi J, Beck M, Leunig M, Nötzli H, Siebenrock KA. Femoroacetabular impingement: a cause for osteoarthritis of the hip. Clin Orthop Relat Res. 2003(417):112–20. This classic paper describes the chondral lesions found in FAI patients and makes the first description of the natural history; that these may be a potential precursor for degenerative disease of the hip in patients with previously classified "idiopathic arthritis". They also hypothesize that early intervention for impingement may decelerate the rate of degeneration of the the hip.

Ganz R, Gill TJ, Gautier E, Ganz K, Krügel N, Berlemann U. Surgical dislocation of the adult hip: a technique with full access to the femoral head and acetabulum without the risk of avascular necrosis. J Bone Joint Surg Br 2001;83:1119–24. This classic paper describes the surgical technique for open surgical hip dislocation, particularly the steps taken to prevent damage to the medial femoral circumflex artery. They also describe the outcomes of their first series of patients to undergo the procedure.

Ganz, R, Huff TW, Leunig M. Extended retinacular soft-tissue flap for intra-articular hip surgery: surgical technique, indications, and results of application. Instr Course Lect 2009;58:241–55. This classic paper describes the surgical technqiue for the extended retinacular soft-tissue flap in open surgical hip dislocations.

This flap allows for elative neck lengthening, subcapital realignment, and intra-articular osteotomies of the femoral head and neck.

Leunig, M, Ganz R. Relative neck lengthening and intracapital osteotomy for severe Perthes and Perthes-like deformities. Bull NYU Hosp Jt Dis 2011;69: S62–7. This classic paper provides further surgical technqiue description for the extended retinacular soft-tissue flap in open surgical hip dislocations. It also describes relative neck lengthening and femoral head reduction osteotomies which can be used in Perthes' deformity.

Smith-Petersen MN. Treatment of Malum Coxae Senilis, Old Slipped Upper Capital Femoral Epiphysis, Intrapelvic Protrusion of the Acetabulum, and Coxae Plana by Means of Acetabuloplasty. J Bone Joint Surg Am. 1936;18:869–880. This classic paper was the first to describe hip pain atribtuted to impingement of the femoral neck on the anterior acetabular margin. The author describes a case series where several patients were treated with resection of portion of the anterior acetabular wall with complete pain relief.

Key Evidence

Clohisy JC, Carlisle JC, Beaulé PE, Kim YJ, Trousdale RT, Sierra RJ, et al. A systematic approach to the plain radiographic evaluation of the young adult hip. J Bone Joint Surg Am. 2008;90 Suppl 4:47–66. This paper is a comprehensive review of how to create the radiographic measurements used to assess plain films of the hip in young patients, including impingement and dysplasia.

Clohisy JC, Knaus ER, Hunt DM, Lesher JM, Harris-Hayes M, Prather H. Clinical presentation of patients with symptomatic anterior hip impingement. Clin Orthop Relat Res. 2009;467(3):638–44. This paper describes the variety and relative frequency of clinical symptoms and physical exam findings associated with hip impingement.

Frank JM. et al. Prevalence of Femoroacetabular Impingement Imaging Findings in Asymptomatic Volunteers: A Systematic Review. Arthroscopy 2015;31:1199–204. This systematic review describes the prevalence of radiographic markers of FAI on asymptomatic patients. They looked at the alpha angle, cam and pincer deformity, and lateral and anterior center edge angles. This study demonstrates the importance of considering patient's history and exam and not only their imaging studies before making the diagnosis of FAI.

De Sa D et al. Femoroacetabular impingement in skeletally immature patients: a systematic review examining indications, outcomes, and complications of open and arthroscopic treatment. Arthroscopy 2015;31:373–84. While the majority of the data published for FAI is performed in adults, this systematic review evaluated outcomes in skeletally immature patients. It demonstrates that both open and arthroscopic surgery can be successful in young patients for the proper indications.

Nwachukwu BU et al. Complications of hip arthroscopy in children and adolescents. J Pediatr Orthop 2011;31:227–31. This paper discusses the unique theoretical risks of hip arthroscopy in skeletally immature patients including iatrogenic slipped capital femoral epiphysis, proximal femoral growth disturbance, and avascular necrosis of the femoral head. It also reviews the incidence of common complications including transient nerve palsy, suture abscess, and instrument breakage.

Pfirrmann CW et al. Cam and pincer femoroacetabular impingement: characteristic MR arthrographic findings in 50 patients. Radiology 2006;240:778–85. This paper utilizes MR arthrography to describe patterns of cartilage injury seen in patients with FAI; particularly lesions at the anterosuperior and superior positions in cam deformity and posteroinferior position in pincer deformity.

Siebenrock KA, Ferner F, Noble PC, Santore RF, Werlen S, Mamisch TC. The cam-type deformity of the proximal femur arises in childhood in response to vigorous sporting activity. Clin Orthop Relat Res 2011;469: 3229–40. This paper evaluated high school aged basketball players versus a control group who did not participate in high level sports. Based upon X-rays and physical exam this study suggests high intensity sports activity during adolescence is associated with a substantial increase in the risk of cam-type impingement.

Sink EL, Beaulé PE, Sucato D, Kim YJ, Millis MB, Dayton M, Trousdale RT, Sierra RJ, Zaltz I, Schoenecker P, Monreal A, Clohisy J. Multicenter study of complications following surgical dislocation of the hip. J Bone Joint Surg Am 2011;93:1132–6. This paper discusses both the types and incidence of complications following open surgical hip dislocation including heterotopic ossification, neuropraxia, trochanter nonunion, infection and deep venous thrombosis. It also demonstrates a 0% incidence of femoral head avascular necrosis.

Take Home Messages

- The diagnosis of femoroacetabular impingement is complex and should rely on a combination of patient's clinical history, physical exam, and imaging findings
- The clinical history of FAI is variable, and often has a significant degree of overlap with acetabular dysplasia, including groin, lateral hip, anterior thigh, knee and back pain
- The physical exam of patients with FAI is often associated with painful and limited hip flexion, as well as a positive anterior impingement test
- Appropriate imaging evaluation for suspected FAI includes a complete X-ray series and may involve a computerized tomography (CT) scan, magnetic resonance (MR) imaging and/or MR arthrogram
- The goal of non-operative treatment is to reduce pain and limit aggravating activities, without changing the patient's range of motion. Options may include non-steroidal anti-inflammatory medications (NSAIDs), physical therapy, injections, and rest/activity modification
- Pre-operative identification of the likely source of a patient's impingement is crucial to successful surgical intervention for FAI and should guide the surgeon towards open surgical dislocation, arthroscopy, or additional procedures including anteverting periacetabular osteotomy or derotational femoral osteotomy

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