Operative treatment of FAI: open hip preservation surgery

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Abstract Femoroacetabular Impingement (FAI) is characterized by abnormal contact of the hip joint. Many etiologies cause this painful condition, which leads to early osteoarthritis. While hip arthroscopy has become the most prevalent way to surgically correct a hip, some presentations of FAI require open surgical hip preservation techniques to fully address the pathology at hand. Certain head neck deformities may require open surgical hip dislocation utilizing a trochanteric slide osteotomy. A retroverted acetabulum may require an open periacetabular osteotomy to gain anteversion and eliminate impingement in the hip joint. Acetabular protrusio may require surgical hip dislocation with rim trimming and a possible valgus intertrochanter osteotomy. The sequelae of Legg-Calvé-Perthes disease causes complex abnormalities about the hip joint, which may require open surgery to address both the intra-articular pathology and the extra-articular pathology. Osteotomies of the proximal femur and acetabulum may all be necessary to restore a hip back to normal morphology. Chronic slipped capital femoral epiphysis (SCFE) may also require open surgical hip dislocations and complex intertrochanter osteotomies to recreate normal morphology.

Keywords Hip preservation · Hip impingement · Femoroacetabular impingement

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Introduction

Ganz and colleagues [1] were the first to describe the concept of femoroacetabular impingement (FAI) as a pathologic disorder characterized by abnormal contact of the hip joint from subtle osseous deformities causing pain leading to the development of end-stage hip osteoarthritis. FAI includes 3 different subtypes: cam impingement from proximal femoral deformities, pincer impingement from focal or global acetabular overcoverage, and combined impingement [1]. The number of studies on the basic science and clinical outcomes of FAI have grown exponentially over the past decade [2].

Ganz and colleagues [1] described the open surgical dislocation to evaluate chondrolabral injury, perform acetabular rim trimming, and perform femoral osteochondroplasty. More recently, several studies have been published on the arthroscopic treatment of FAI, and the clinical outcomes have been comparable with the open approach [2]. Although hip arthroscopy has made great advances in the past decade, there are a number of more severe deformities that cannot be addressed arthroscopically and require an open technique. Developmental deformities including acetabular dysplasia, acetabular retroversion, acetabular protrusio, femoral valgus, excessive femoral anteversion, sequelae of Legg-Calvé-Perthes disease and chronic slipped capital femoral epiphysis are all currently treated by open hip surgery. The goal of these joint-preserving procedures is to improve the pathomechanics of the underlying hip deformity. The present review article summarizes each of these pathomorphologic conditions, the surgical techniques used to treat each condition, and the published clinical outcomes.

Femoroacetabular impingement

Patients with FAI generally complain of groin pain but may also have pain located in the lateral and posterior aspect of the hip and pelvis. Most patients deny any trauma but report

an insidious onset of hip pain for several months or even years. The pain is generally worsened with flexion based activities such as sitting, squatting, stair climbing, and rotational movements such as running, cutting, pivoting, or twisting. During physical examination, the impingement test has been described to reproduce pain with the hip flexion to 90°, adduction, and internal rotation (FADDIR) forcing the anterior femoral neck area against the acetabular rim [3]. The resulting sensation of pain may be caused by shear or compression of the acetabular labrum, which possess both proprioceptive and nociceptive nerve fibers, similar to the knee meniscus [4]. Furthermore, a torn acetabular labrum and defects of the cartilage are sequelae of a chronic anterior FAI and have been recognized as a source of pain in the hip and are related to the development of osteoarthritis [5–7]. The posterior impingement test has been described to cause pain with hip extension and external rotation [3]. Radiographic evaluation is critical to understand the specific pathomorphology. The lateral center edge angle and Tönnis angle are used to characterize the acetabular morphology and the cross over sign is used to diagnose acetabular retroversion. Cam deformities can be confirmed by measuring the alpha angle on various radiographic views of the hip, and an alpha angle larger than 50° is considered to be abnormal [8].

The surgical hip dislocation was originally described by Ganz and colleagues [7] and constituted the first surgical technique for the treatment of FAI. Open surgical dislocation is the foundation for open hip preservation surgery as it allows the surgeon to access the hip joint and address any intra-articular pathology as well as extra-articular pathology causing impingement. The patient is typically positioned in lateral decubitus and a standard Gibson approach is performed; which spares the anterior half of the gluteus maximus [9]. A trochanteric flip osteotomy is utilized to facilitate an anterior hip dislocation. The obturator externus muscle remains intact to the piriformis fossa, and therefore, protects the femoral head from avascular necrosis [7, 10]. The main blood supply to the femoral head, the medial circumflex artery (MCFA), runs through this muscle before perfusing the capsule, neck and head. Laser Doppler flowmetry has been used to confirm that this operation does not disrupt the blood supply to the femoral head when proper technique is performed [10]. A Z-shaped capsulotomy is performed to directly visualize the joint [7]. The main benefit to this operation is that it gives a 360° view of both the femoral head and acetabulum. No other operation provides such broad visualization for performing intra-articular hip preservation procedures. Toe-touch weight bearing is required for 6–8 weeks after surgery to allow for the osteotomy to heal. Thereafter, patients are able to full weight bear and physical therapy is typically prescribed.

Outcomes following surgical hip dislocation have been extensively studied and show promising results. Beck et al.

[11] reported good to excellent midterm results in 13 of 19 patients treated with surgical hip dislocation with an average follow-up of 4.7 years. Kempthorne et al. [12] showed significant improvements in 53 patients' WOMAC scores (35 points, $P=0.0039$) at 4 years follow-up. Furthermore, Bedi et al. [13] reported a significant difference between preoperative and postoperative radiographs in 30 patients who underwent surgical hip dislocation. The extended-neck lateral alpha angle was reduced by a mean of 21.2° (30.7 %, $P<0.05$), the anterior femoral head-neck offset was improved by 6.56 mm (108 %, $P<0.05$), and the beta angle was increased by a mean of 18.35°.

Outcomes of open treatment of FAI in an athletic population have also been reported [14]. Five professional ice hockey players were able to return to unrestricted practice without symptoms at 6.7 months and return to their first competitive game after a mean of 9.6 months. Pre-operative range of motion was recovered at 10.3 months. At an average follow-up of 2.7 years, 3 of the 5 players had returned to their prior level of competition. More recently, Naal et al. [15] reported on the return to sport in 22 male athletes after surgical hip dislocation with a mean follow-up of 45.1 months. At follow-up, 95 % of the patients were competing professionally and 82 % were satisfied with their hip surgery.

Complications following open hip dislocation are common and include trochanteric bursitis secondary to hardware at the osteotomy site (26 %), osteotomy nonunion (3 %–20 %), and Brooker grade IV heterotopic ossification (3 %) [16–19].

Acetabular retroversion

True acetabular retroversion is an uncommon form of dysplasia that causes excessive anterolateral coverage for the femoral head and undercoverage of the posterior aspect of the hip. When the hip is in a position of flexion and adduction, the femoral head abuts on the anterior acetabular wall causing hip pain. Patients are usually symptomatic when they perform more high demand activities and activities requiring deep flexion. They may present with groin/buttock pain symptoms that are gradual in onset. The diagnosis of true acetabular retroversion is confirmed on an AP pelvis radiograph with a posterior wall sign and/or a cross over sign. If presenting late, the radiographs should also reveal fragmentation of the prominent anterior acetabular rim [3, 20].

Excessive acetabular rim trimming of the anterior wall may cause an unstable hip by creating anterior undercoverage with an existing posterior wall undercoverage. Surgical correction of a retroverted acetabulum requires a reverse periacetabular osteotomy to address the anterior hip impingement while maintaining hip stability [3, 20, 21]. The reverse periacetabular osteotomy is typically performed through a Smith-Peterson

approach to access the hip. Osteotomies are performed to facilitate a 10°–20° reorientation of the acetabular fragment. A surgeon achieves this result by flexing and internally rotating the fragment [2]. Biplanar fluoroscopy is required to verify that the acetabulum is appropriately anteverted [22••]. A hip arthrotomy can be performed in conjunction with a acetabular osteotomy allowing for any necessary additional intra-articular surgical interventions to be performed. Patients remain partial weight bearing with crutches for 6 weeks post-operatively and full weight bearing with 1 crutch for an additional 6 weeks [23].

Siebenrock et al. [21] showed good to excellent results in 26 of 29 patients with an average follow-up of 30 months. The average Merle d'Aubigne score improved from 14.0 points to 16.9 points at follow-up. Cross-over sign was eliminated in all but 4 patients. In the remaining 4, it was seen only in the superolateral aspects of the acetabulum. Furthermore, Peters et al. [24] showed a statistically significant improvement in the Harris hip score, from 54 to 86, at 1-year follow-up in 83 patients who underwent a periacetabular osteotomy for FAI. A statistically significant improvement in radiographic measurements was also noted in the acetabular index, center-edge angle, anterior center-edge angle, and Sharp's angle on AP roentgenography. Following surgery, 96 % of patients that had radiographic evidence of retroversion were corrected so that all radiographic parameters showed an anteverted or neutral acetabulum [24].

Major complications are common for this operation and occurred in 6 %–37 % of cases. The most common complications include heterotopic ossification, wound hematomas, transient nerve palsies (femoral and sciatic), intra-articular osteotomies, loss of fixation, and malreduction [16]. Nonunion rates of up to 24 % of either the pubis or ischium have been reported [24]. Further, 12 %–28 % of patients require a re-operation due to symptomatic hardware [20].

Protrusio acetabuli

Protrusio acetabuli is a condition characterized by relative medialization of the acetabulum. It is identifiable on AP radiographs of the pelvis when the acetabular line projects medial to Kohler's line. The prevalence of protrusio is unknown. The etiology of protrusio acetabuli is unknown but may include infection, neoplasm, inflammatory, genetic and metabolic disorders, and trauma [25]. Patients with protrusio typically present with complaints of groin pain and stiffness with activity. Before surgical intervention is considered it is important to search for an identifiable cause, and the work up includes a thorough neurologic and cardiovascular exam as well as blood testing. If a cause is identified, treatment of the underlying condition is the first step. Surgical decision-making is predominately dependent on the patient's age and

the amount of hip degeneration. Options of surgical treatment include tri-radiate closure in skeletally immature patients, valgus intertrochanteric osteotomies, hip joint preservation surgery, and hip arthroplasty [25–27].

Steel [28] followed 19 hips until skeletal maturity that underwent tri-radiate cartilage fusion for protrusio. After closure, 12 of the 19 hips were considered to be normal, 4 were downgraded to an "acetabular deepening" and 3 remained as protrusio. The only postoperative complication found in the literature was transient femoral nerve palsy found in 10 % of cases [28].

A skeletally mature patient without hip degeneration should be offered a surgical hip dislocation and/or a valgus intertrochanteric osteotomy. A surgical hip dislocation allows the surgeon to trim the entire acetabular rim to reduce its depth and to perform a labral repair or reconstruction [29]. Some cases may require femoral osteochondroplasty and relative lengthening of the femoral neck to allow for adequate clearance [25]. A valgus intertrochanteric osteotomy (VITO) lateralizes the femur to restore normal mechanical alignment of the hip joint and will facilitate femoroacetabular clearance. To perform the VITO, the patient is positioned supine and a direct lateral approach is used by splitting the vastus lateralis to access the lateral femur. Two k-wires are positioned so that they act as a guide for the osteotomy cuts. A saw may be used to cut the closing wedge; the proximal portion closes the wedge by abducting and is forced itself to fall into valgus. A plate is fixed to the femoral shaft to secure the osteotomy. The patient is made toe-touch weight bearing for the first 6 weeks and then full weight bearing [30].

Results of valgus intertrochanteric osteotomies have been mixed. Rosemeyer et al. [31] reported good to excellent results in 21 of 25 hips at 6 year follow-up who underwent a VITO. Hooper and Jones [32] reported that 7 of 9 patients undergoing a VITO had fair to poor results. McBride et al. [26] reported on 19 hips that underwent a VITO for acetabular protrusio. All but 2 patients were satisfied with their decision to this hip preserving procedure at 3 years after surgery. Complications were reported as an 11 % superficial wound infection rate, a 19 % with a trendelenburg gait, and a 15 % reoperation/revision rate [26].

Patients presenting late in the disease process with degenerative changes or those found to have an inflammatory arthropathy should be offered a total hip arthroplasty [26].

Sequelae of Legg-Calvé-Perthes disease

Legg-Calvé-Perthes disease (LCPD) is an idiopathic childhood hip disorder that causes osteonecrosis of the femoral head. Deformation is thought to result from hip loading in the presence of osseous changes secondary to relative avascularity. Typically a patient presents with mild pain, limited range

of motion, and a coxalgic gait. It is a diagnosis of exclusion and all other causes for hip osteonecrosis must be investigated and ruled out. Although there is potential for the hip to remodel, residual deformity in the skeletally mature patient is common. Deformity varies from a high riding trochanter, a short femoral neck, and a misshapen femoral head to acetabular dysplasia, retroversion, and incongruity. These abnormalities often cause impingement, instability, mechanical symptoms, and dysfunction of the hip [33•, 34]. The Stulberg classification is used to predict the progression of osteoarthritis in a deformed hip secondary to LCPD. Class I is a completely normal hip; Class II is a hip with a spherical head but with some abnormality of the femoral head, neck, or acetabulum; Class III is nonspherical mushroom shaped/umbrella shaped femoral head; Class IV is a flat femoral head with abnormalities of the femoral neck and acetabulum; and Class V is a flat femoral head without abnormalities of the femoral neck and acetabulum [35]. Class I and II hips are functionally normal and are usually without any pain later in life. Class III and IV hips show progression of subluxation and typically develop mild to moderate arthritis later in life. Class V hips usually progress to end stage arthritis later in life. It is thought that this occurs because a normal acetabulum does not accommodate for a misshapen femoral head [35].

Surgical intervention should be reserved for symptomatic patients. It is imperative to fully assess the symptoms and radiographs of a patient so that adequate pre-operative planning can occur and all pathomorphologies can be addressed during the planned operation [33•].

Intra-articular impingement is due to asphericity of the femoral head and acetabulum. Cam deformities are the most common abnormality but pincer deformities often occur as well. Typical surgical treatment includes surgical hip dislocation with osteoplasty of the affected femoral head-neck junction and acetabulum. The remainder of the correction is tailored to the specific deformity present. In the setting of femoral retroversion a valgus osteotomy is necessary; if acetabular dysplasia is present a periacetabular osteotomy is indicated; and in the setting of acetabular malrotation an acetabular rim trim is indicated [33•, 36].

Extra-articular impingement is usually due to abnormalities of the greater and lesser trochanter. A high riding greater trochanter causes impingement on the ischium and posterior acetabulum and causes abductor weakness. This can be corrected advancing the trochanter distally and laterally, which would relatively lengthen the femoral neck and place the hip abductor at a greater mechanical advantage [37].

Most surgical techniques for the sequelae of LCPD starts with the patient positioned lateral decubitus utilizing the same approach as described for a surgical hip dislocation. All intra-articular abnormalities can be addressed with this approach. A relative lengthening procedure of the femoral neck or a distalizing procedure of the lesser trochanter to resolve extra-

articular pathology requires additional visualization of the femur. One must mobilize an extended retinacular flaps about the head, neck, and greater trochanter to continue to preserve the MCFA blood supply while adequately exposing the intertrochanter region [38]. A relative lengthening of the trochanter involves resecting a trapezoidal segment of the superior head-neck with osteotomes in a sagittal direction. The goal of the trapezoid is to construct a femoral head that closely contours to the retained inferior head. The surgeon positions the resected bone superomedially so that the femoral head has little to no step off and is secured with multiple screws. The trochanter osteotomy may be placed in a more distal and lateral position and also re-secured with multiple screws. If the acetabulum does not fit properly over the newly constructed femoral head it is advised to perform a periacetabular osteotomy at this time similar to the procedure described above. The patient must remain toe touch for 6–8 weeks [39].

Leunig et al. [39] reported 14 cases of patients undergoing a relative lengthening operation of the femoral neck. Eight hips also had a PAO performed at the same time. All osteotomies healed within 8 weeks and none developed osteonecrosis by 3 year follow-up. Further, all patients reported an improvement in motion and all were without substantial pain.

Complications are similar to the other osteotomies about the femur described in this review. They include pseudoarthrosis, painful hardware, superficial infection, and re-operation [39].

Chronic slipped capital femoral epiphysis

Slipped capital femoral epiphysis (SCFE) is a common hip disorder of early adolescents. A failure of the growth plate allows the metaphysis to slip anterosuperiorly or posteroinferiorly while the epiphysis remains in the acetabulum. The incidence in North America is as high as 10 in 100,000 people. It most often affects overweight adolescent boys. Once diagnosed, in situ pinning is indicated to stop further progression of the slip. Most often a complex deformity is formed after the hip remodels. The result in an abnormality at the femoral head-neck junction causing impingement [40].

Surgical treatment options for chronic SCFE depend on the severity of the deformity. A small slip angle can be treated arthroscopically but if the slip angle is sufficiently large, open surgical techniques are necessary for better visualization [41•]. Surgical hip dislocation, femoral osteotomy, or a combination of the 2 can be used to correct intra-articular and extra-articular impingement. The proximal femoral osteotomy alters the lateral head/shaft angle, and therefore, prevents femoroacetabular impingement.

An intertrochanteric femoral osteotomy uses a standard lateral approach through the vastus lateralis with the patient in the supine position. A wedge of bone is removed from the

intertrochanteric region to correct for flexion, varus, and external rotation deformities. Any remaining rotational deficiency is corrected by internally rotating the distal fragment. A blade plate can be used to fix the osteotomy in place [42]. After surgery, the hip is fully immobilized in flexion, abduction and internal rotation for 8–12 weeks. The patient must wear a Thomas splint for an additional 12 weeks. Progressive weight bearing is usually allowed immediately after surgery [43].

Outcome studies show favorable short to midterm results in these open hip preservation surgeries for the treatment of chronic slipped capital femoral epiphysis. Spencer et al. [44] reported on 19 patients with FAI who underwent open surgical hip dislocation and 12 had FAI secondary to chronic SCFE deformity. Most (63.2 %) showed improvement in pain and function at 12 months postoperatively. Rebello et al. [45] reported on 29 patients with chronic SCFE that underwent femoral head-neck osteochondroplasty, intertrochanteric osteotomy, femoral neck osteotomy, and open reduction internal fixation for correction. The average pre-operative to post-operative WOMAC score improvement was 4.4. Kartenbender et al. [43] reported on the long term results of 35 patients (39 hips) treated with corrective intertrochanteric osteotomy for severe chronic SCFE. Patients were re-examined at a mean of 23.4 years after surgery. Nine hips had no pain, 22 hips had slight pain with exercise, 4 hips had moderate pain with exercise, and 4 hips had debilitating pain. The authors concluded that a majority of patients had excellent to good results [43]. Schai et al. [36] reported the results of 51 patients who underwent an intertrochanteric osteotomy for chronically impinging SCFE at an average of 24 years. 55 % of patient showed no progression to degenerative disease, 28 % had moderate progression, and 17 % had severe osteoarthritis.

Surgically related complications have been reported in 48 % of patients undergoing intertrochanteric osteotomies. 29 % had acute joint space narrowing accompanied by loss of motion, 5 % had a superficial infection, 5 % had a loss of reduction, 10 % had a delayed union, and 5 % had a bone cyst develop in the femoral neck [46].

Conclusions

Femoroacetabular impingement surgery using open hip preservation techniques have been reported to relieve pain, improve function, and decrease the risk for development of osteoarthritis. Patients presenting with large complex deformities and painful symptomatology require larger exposures and more radical correction than can be afforded by hip arthroscopy. Due to the invasive nature of the surgery, there is significantly greater risk for complications compared to hip arthroscopy. A surgeon must balance the risks and benefits of each operation and individualize the treatment strategy to fit

each patient's complaints and pathomorphology. Overall, these hip preservation procedures can provide good to excellent outcomes but need to be performed by experienced surgeons at major referral centers.

Compliance with Ethics Guidelines

Conflict of Interest Michael D. Hellman declares that he has no conflict of interest. Andrew J. Riff declares that he has no conflict of interest. Bryan D. Haugom declares that he has no conflict of interest. Rikesh Patel declares that he has no conflict of interest.

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- Of importance
- Of major importance

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