[Orthopaedic Surgery]

Current Concepts in Hip Preservation Surgery: Part I

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Context: An evolution in conceptual understanding, coupled with technical innovations, has enabled hip preservation surgeons to address complex pathomorphologies about the hip joint to reduce pain, optimize function, and potentially increase the longevity of the native hip joint. Technical aspects of hip preservation surgeries are diverse and range from isolated arthroscopic or open procedures to hybrid procedures that combine the advantages of arthroscopy with open surgical dislocation, pelvic and/or proximal femoral osteotomy, and biologic treatments for cartilage restoration.

Evidence Acquisition: PubMed and CINAHL databases were searched to identify relevant scientific and review articles from January 1920 to January 2015 using the search terms *hip preservation, labrum, surgical dislocation, femoroacetabular impingement, peri-acetabular osteotomy*, and *rotational osteotomy*. Reference lists of included articles were reviewed to locate additional references of interest.

Study Design: Clinical review.

Level of Evidence: Level 4.

Results: Thoughtful individualized surgical procedures are available to optimize the femoroacetabular joint in the presence of hip dysfunction.

Conclusion: A comprehensive understanding of the relationship between femoral and pelvic orientation, morphology, and the development of intra-articular abnormalities is necessary to formulate a patient-specific approach to treatment with potential for a successful long-term result.

Keywords: hip preservation; peri-acetabular osteotomy; surgical dislocation; labrum; arthroscopy

The influence of abnormal joint morphology on the progression of osteoarthritis has been postulated for years.[6,18,27,36,40,47,67,68,78] In addition, compensatory changes to the peri-articular myotendinous envelope and lower extremity kinematics are becoming better understood.[6,31,46,50] Often, pathologies within the hip joint (labral-chondral injuries, synovitis, ligamentum teres tears) are associated with underlying abnormalities of bony morphology, rotation, version, or alignment. Modern hip preservation techniques aim to restore an optimal relationship between structure and joint kinematics. These techniques have shown promise for providing a durable solution for pain and dysfunction while avoiding the limitations and disadvantages inherent to joint arthroplasty.[28,55,61,80]

ANATOMY AND BIOMECHANICS

Hip pathomorphology may interfere with physiologic motion due to anatomic conflict between the femoral head-neck junction and the acetabular rim. Soft tissue impingement, while less well understood, may also further restrict motion and lead to inhibition patterns of weakness and instability.[48] Compromised joint stability can result in increased femoral translation, capsular attenuation, and increased shear stresses on the articular cartilage.[30] In addition, atraumatic instability may increase the demand on adjacent peri-articular muscle groups, leading to compensatory adaptations during functional tasks.[44,76] Over time, these cumulative biomechanical changes may result

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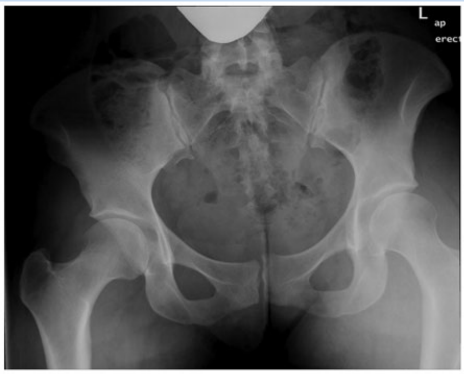

Figure 1. A 25-year-old woman with left lateral hip pain and right anterior groin pain. Plain radiographs demonstrate relative acetabular overcoverage on the right and undercoverage on the left due to leg length inequality and pelvic tilt. Acetabular undercoverage of the left hip placed increased demand on the peri-articular myofascial envelope (TFL, GMax, and ITB) and resulted in fatigue overload of these structures. Overcoverage on the right hip resulted in symptomatic FAI with labral and chondral injuries. Left proximal femoral shortening osteotomy corrected pelvic obliquity, normalized coverage, and rebalanced peri-articular myofascial stabilizers. FAI, femoroacetabular impingement; GMax, gluteus maximus; ITB, iliotibial band/complex; TFL, tensor fascia lata.

in progressive damage to intra-articular labral and chondral structures.[5,50]

During functional movements, postural control is regulated by dynamic force coupling, allowing distribution of imparted stresses and torque.[26] Efficient mobility of the hip requires 40° to 50° of frontal plane motion and tolerance of one-third of an individual's body weight during stationary double-leg stance.[82] During unassisted stance and upright tasks, contributions of the psoas and abductor complex stabilize the lumbar spine while maintaining stability of the trunk in an erect position.[2] Joint reactive forces reach a peak during toe-off and heel strike, necessitating increased activation of the adductor group and pectineus.[82] Forward propulsion during ambulation requires the peri-articular musculature to generate a force of at least 6 times an individual's mass to counteract the body's weight and maintain pelvic stability.[3] Cooperation between complementary peri-articular muscular groups and torque provided by tensioning of the iliotibial band/complex are necessary to maintain pelvic equilibrium.[51] Abnormal pelvic elevation or depression compromises pelvic stability by limiting contributions from osseous structures and disrupting the balance between dynamic stabilizers (Figure 1). When pelvic elevation exceeds normal alignment by 15°, muscular demands must increase to maintain pelvic symmetry.[42] Pelvic depression escalates fascial tension required to maintain pelvic stability with minimal to no recruitment of desirably involved musculature.[51]

The combination of pathologic joint kinematics, dysfunctional peri-articular force coupling, and joint incongruence propagates altered joint reaction forces and potentially accelerates degenerative changes.[32]

CLINICAL MANIFESTATION

Abnormal arthrokinematics are an expected consequence of structural abnormalities, muscular imbalances, and pain associated with hip pathologies.[64] The "layer concept"[31] has been proposed as a theoretical model to understand the presence and progression of hip joint dysfunction. Abnormalities involving any layer may lead to compensatory reactions from others and eventually result in linked pathomechanical changes within the proximal or distal segments of the kinetic chain. Antalgic gait patterns frequently manifest as a result of mechanical alterations and associated dynamic neuromuscular impairment. Gait abnormalities are often a product of pain or insufficient dynamic stability. Lateral trunk movement toward the dysfunctional hip is a strategy commonly employed to unload intra-articular pressures by displacing the center of gravity and enhance the mechanical advantage of the abductor complex when gluteal activation is poor.[51,84] With gluteal weakness, adductor magnus activity will increase to maintain pelvic stability. Abductor strength may be compromised by abnormal femoral head positioning due to increased activation angle of the gluteus medius (GMed) caused by the augmented abductor lever arm.[66] Supplementary recruitment of internal rotators is also employed as a compensatory strategy to increase abductor efficiency.[17,34] Altered motor patterns that facilitate muscular disuse and dysfunction are further potentiated as the result of neuromuscular inhibition and habitual preference.[49,52]

PATHOPHYSIOLOGY

Acetabular Dysplasia

In acetabular dysplasia, there is insufficient containment of the femoral head by the acetabulum, creating a focused distribution of joint reactive forces across a narrow segment of articular cartilage (Figure 2). Dysplasia may be characterized by focal regions of insufficient volume within the acetabular fossa or global undercoverage, where there is diffuse insufficiency of bony containment. Patterns and location of symptoms as well as compensatory peri-articular adaptations are often reflective of the specific anatomic region of structural instability.[24] Uncorrected symptomatic acetabular dysplasia may increase the risk of functional impairment and degenerative joint disease due to associated labral hypertrophy and pathology, bony impingement, and capsular attenuation.[25,30,37,54,81] Previous studies have linked acetabular dysplasia to premature osteoarthritis and the increased likelihood of requiring arthroplasty.[20,23,25,52,69,79] Acetabular dysplasia is responsible for 20% to 50% of Americans suffering from symptomatic hip osteoarthritis.[45]

Figure 2. A 16-year-old swimmer with symptomatic right hip acetabualar dysplasia.

Figure 3. A 17-year-old soccer player with excessive proximal femoral valgus and concomitant symptomatic femoroacetabular impingement.

Alteration of Proximal Femoral Alignment

Excessive anteversion, retroversion, or inclination of the proximal femur may lead to chronic pain, instability, and progressive functional decline[32,40,41,57] (Figure 3). Increased sheer and translational forces caused by joint incongruity may accelerate degradation of the joint as a result of focused compression on the articular cartilage.[79] Proximal femoral anteversion, defined as greater than 25°, referenced off the ipsilateral femoral condyles, has been linked to atraumatic anterior hip instability and posterior impingement, while femoral retroversion may predispose to anterior impingement, reduced internal rotation, and posterior hip instability.[12,32,53,56] The inclination angle, defined as the angle subtended by the femoral neck and shaft of the proximal femur, affects leg length and influences dynamic abductor function and force coupling.[12,32] Clinically, abduction is limited due to trochanteric-pelvic impingement and intervening soft tissues, which discourages abductor muscular recruitment. Coxa valga is often asymptomatic, but may require surgical correction to improve distribution forces across the weightbearing surface of the joint and limit chondrolabral injury.[59,75] Excessive valgus angulation can perpetuate mechanical instability and ultimately lead to focal chondral loss due to edge loading at the lateral margin of the acetabular rim.[22] Coxa vara, on the other hand, is less common but may predispose to trochanteric-pelvic impingement or, due to increased offset, lead to peritrochanteric pain and iliotibial band/complex contracture.[58]

Femoroacetabular Impingement

Morphologic alterations of the proximal femur and/or acetabulum may lead to pathologic anatomic conflict during dynamic activities (Figure 4).[62] Progressive chondral and labral injuries may ultimately occur, leading to pain, joint dysfunction, and alterations in adjacent body segments within the kinetic chain. Impaired motion between the proximal femur and acetabulum may also lead to reactive changes in the other portions of the "pelvic joint," including pubic symphysis, pelvic brim, sacroiliac joint, and lumbar spine.[11,46] The location of impingement may be intra-articular, including the proximal femur and acetabulum, or extra-articular, most commonly involving the proximal femur and anterior inferior iliac spine, between the greater trochanter and pelvis and between the ischium and lesser trochanter. Femoroacetabular impingement (FAI) has been proposed as a significant contributor to the development of premature hip arthritis due to repetitive forceful collision between the proximal femur and acetabulum, leading to labral-chondral injury and resultant joint deterioration.[41]

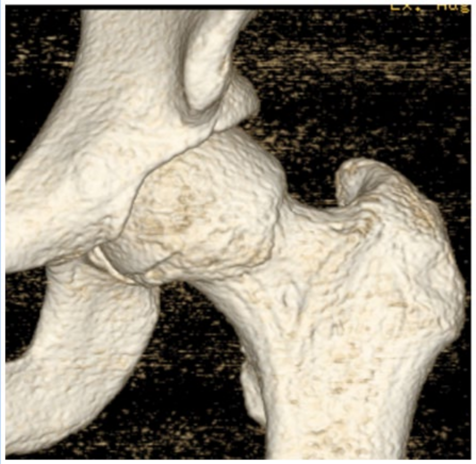

Figure 4. A 28-year-old recreational athlete with symptomatic left hip femoroacetabular impingement (FAI) and reduced femoral head-neck demonstrated on computed tomography with 3-dimensional reconstruction.

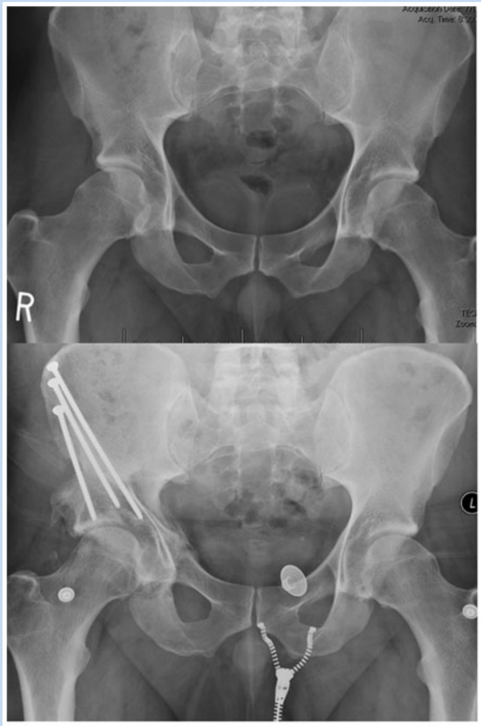

Figure 5. Pre- and postoperative radiographic images of a 32-year-old man with a low-volume acetabulum and concomitant femoroacetabular impingement (FAI) treated with arthroscopic FAI decompression and peri-acetabular osteotomy to correct structural instability, abnormal bony morphology, and intra-articular labral-chondral injury.

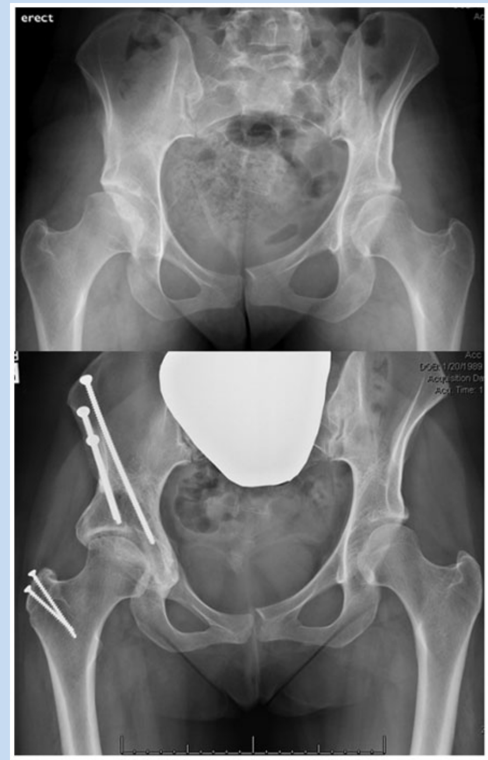

Figure 6. Pre- and postoperative images of a 26-year-old woman with acetabular dysplasia and AVN of the femoral head treated with peri-acetabular osteotomy and femoral head OATS using a vessel-sparing SD. AVN, avascular necrosis; OATS, osteoarticular allograft transplantation system; SD, surgical dislocation.

JOINT-PRESERVING TECHNIQUES

Peri-acetabular Osteotomy

The Bernese peri-acetabular osteotomy (PAO),[24] often referred to as the Ganz osteotomy, is currently the preferred technique for large-scale correction of acetabluar dysplasia.[1,39] It has been championed for its ability to affect global improvement in femoral head coverage and balance force concentration through the weightbearing portion of the femoral head. By preserving the integrity of the posterior column of the pelvis, this osteotomy allows earlier weightbearing through preservation of an intact posterior column and a more aggressive rehabilitative approach. In addition to its utility in low-volume acetabulum conditions such as acetabular dysplasia, the PAO has been used in FAI to offset dysmorphism of the proximal femur as well as aid in correction of global anteversion or retroversion of the acetabulum (Figure 5).[77] There are occasions where structural instability exists in the presence of concomitant avascular necrosis (AVN). PAO may be used in conjunction with surgical dislocation and osteoarticular allograft transplantation system (OATS) (Figures 6 and 7). A reorientation procedure may lend itself to the redistribution of force across the acetabulum and potentially decelerate joint degeneration seen in acetabular dysplasia.[80] A PAO may be performed as an isolated procedure with exposure of the anterior hip via arthrotomy or in conjunction with hip arthroscopy for minimally invasive joint access and central and peripheral compartment work (Figure 8). Clinical studies have demonstrated a high rate of intra-articular pathology at the time of arthrotomy or arthroscopy.[29,74] Failure to address concomitant intra-articular joint disease at the time of reorientation osteotomy may lead to persistent pain and incomplete recovery.[29,43]

The decision whether to utilize arthrotomy or arthroscopy as an adjunct to PAO is largely surgeon- and resource-dependent. In addition, arthroscopy can confirm the suspected pattern of joint mechanics by demonstrating edge-loading on articular cartilage and further help refine the necessary corrective rotation of the PAO. Patients with larger body habitus may also benefit from an arthroscopic approach because of more challenging visualization with an open approach and arthrotomy.

Proximal Femoral Osteotomy

Derotational osteotomy techniques are performed for excessive anteversion or retroversion, whereas varus/valgus correction of

Figure 7. Intraoperative images depicting the exposed femoral head after osteoarticular allograft transplantation system (OATS) with excellent graft contour and smooth press-fit.

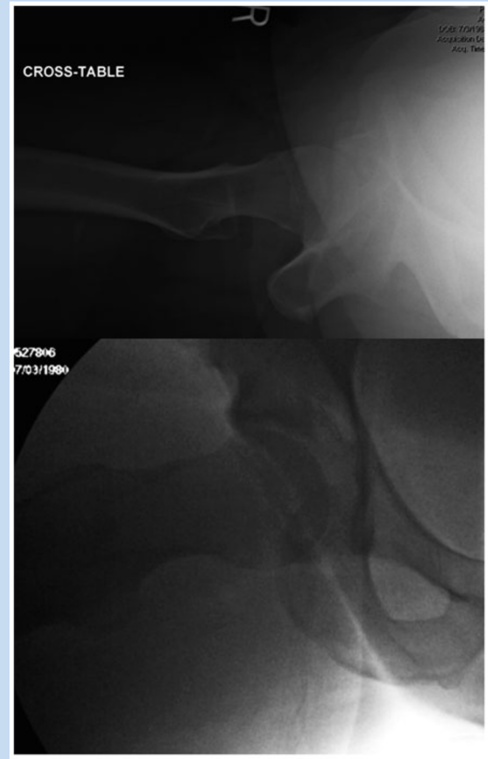

Figure 8. Preoperative lateral and intraoperative image demonstrating reduced femoral head-neck offset and subsequent correction using arthroscopic decompression.

Figure 9. Patient from Figure 2 after varus proximal femoral osteotomy. This patient also underwent arthroscopic femoroacetabular impingement decompression and labral repair.

angulation redirects the femoral head to modify contact surfaces, diminish shear vector, and optimize the biomechanical advantage of the peri-articular myotendinous envelope (Figure 9).[59] A varus osteotomy may decrease edge-loading by recentering the femoral head within the acetabulum.[89] This may consequently lead to decreased gluteal muscle recruitment. Conversely, a valgus osteotomy may shorten and enhance efficiency of the abductor lever arm and increase joint congruence through distalization of the greater trochanter.[59] Proximal femoral osteotomies may improve the mechanical environment of the joint and delay total hip arthroplasty.[89] Conditions such as Legg-Calve-Perthes (LCP) and slipped capital femoral epiphysis (SCFE) are often associated with global deformities of the femoral head and neck and may benefit from proximal femoral osteotomy. Proximal femoral osteotomy is a powerful tool that can be used to reorient the region of femoral-sided impingement away from conflicting acetabluar segment, thus allowing indirect decompression of FAI.[57]

Cartilage Restoration

Functional outcome studies after cartilage restoration of the hip are sparse. Microfracture, OATS, autologous chondrocyte techniques (ACT), and matrix-associated autologous chondrocyte implantation (MACI) have been increasingly applied in the knee and ankle with midterm success rates as high as 90%.[8,19,35,71,86] These cartilage restoration techniques have been applied to the hip with encouraging short-term clinical outcomes.[16,63,72] Femoral head OATS has a success rate of 80% in patients with nonsteroid-induced osteonecrosis (see Figure 7).[63] Microfracture of the hip also has favorable outcomes

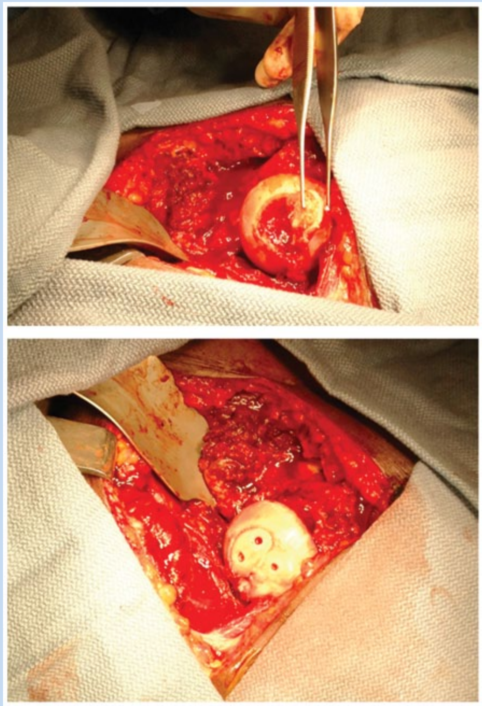

Figure 10. A 16-year-old soccer player with large osteochondral defect of the femoral head. The lesion was noted to have a stable articular surface and viable subchondral bone. Therefore, drilling and bioabsorbable compression screw fixation was used to stabilize the lesion.

for both femoral head and acetabular defects.[16,72] However, for larger lesions, OATS[63] or ACI[14,71] procedures may provide a more durable solution. (Figure 10).

Surgical Dislocation

Traditionally, FAI was treated with osteoplasty of the acetabular rim and/or proximal femur utilizing an open vessel-sparing surgical dislocation (SD), usually via trochanteric osteotomy.[38] In some centers, SD remains the gold standard for gaining circumferential access to the femoral head and permits unobstructed visualization of the central compartment of the hip for treatment of labral and chondral injuries. Studies comparing open versus arthroscopic femoral osteoplasty techniques have shown equivalence in bony correction, although for global femoral head deformities, SD remains a preferable means of addressing superolateral and posterosuperior abnormalities.[7,13,38,57] Furthermore, sequelae of LCP, SCFE, or AVN are often associated with relative femoral neck shortening, which can contribute to ischiofemoral, trochanteric-pelvic, and other iterations of extra-articular FAI (Figure 11). A trochanteric osteotomy is often used as a technical step in this approach and can later be distalized to increase the mechanical advantage of the hip abductor complex and achieve "relative femoral neck lengthening," effectively minimizing extra-articular impingement sources (Figure 12).[2]

Figure 11. A 14-year-old girl demonstrating sequelae of treatment for unstable slipped capital femoral epiphysis (SCFE) with subsequent severe rotational and structural abnormalities of the proximal femur.

In select individuals who demonstrate normal femoral neck length and offset, SD can be accomplished without trochanteric osteotomy, which can have important implications for rehabilitation strategies (Figure 13). Using a modified Watson-Jones approach,[10] fibers of the hip abductor complex are elevated away from the iliocapsularis and anterior capsule. If tissue mobility allows, the trochanter can be left intact, which can facilitate more aggressive rehabilitation as it eliminates the need to achieve bony union prior to advancing weightbearing. However, patient selection is crucial with this approach, since obese patients or patients with less compliant soft tissues are typically not appropriate candidates for this technique and would be better served with trochanteric osteotomy. Furthermore, trochanteric osteotomy is a key technical step in achieving a relative femoral neck lengthening in patients with coxa breva and should be utilized when this clinical scenario is present.[4,33]

One of the most controversial uses of SD in the hip is in the treatment of acute SCFE. A modified Dunn technique can be used to gain access to the unstable and slipped femoral head and neck.[88] A portion of the neck is shortened, restoring proper anatomic positioning of the femoral head on the neck. Potential advantages of this procedure include the reduced need of further

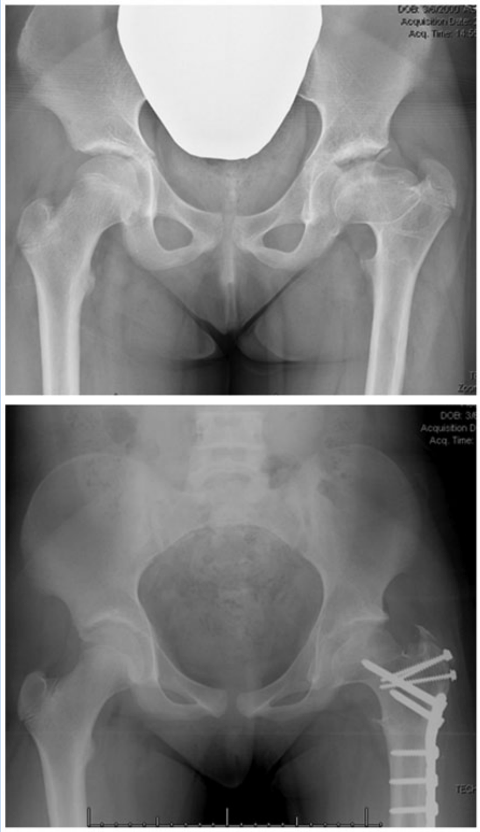

Figure 12. A 15-year-old girl demonstrating sequelae of Legg-Calve-Perthes with severe femoral head deformity, coxa breva, and rotational abnormality of the proximal femur. Treatment consisted of osteochondroplasty of the femoral head via surgical dislocation, relative femoral neck lengthening, and proximal femoral osteotomy.

Figure 13. A 26-year-old woman with a history of graft-versus-host disease who developed widespread heterotopic bone formation as a result of her treatment. She underwent bilateral open femoracetabular impingement decompression via surgical dislocation without the use of trochanteric osteotomy.

surgery to correct residual deformity. In acute SCFE, this procedure may reduce the rate of AVN of the femoral head.[60]

Arthroscopy

As FAI became recognized as a causative factor in the progression of idiopathic osteoarthritis,[41] application of arthroscopic techniques has evolved to correct FAI. Correction of structural pathomorphology via reorientation and restoration procedures may provide limited benefit if underlying intra-articular pathology is left unaddressed (Figure 14).[83] Arthroscopic labral preservation with capsulorrhaphy may benefit select candidates with borderline acetabular dysplasia.[30] In patients with more severe acetabular insufficiency, arthroscopic treatment of labral and chondral abnormalities is more controversial,[15] and careful patient selection and counseling regarding potential risks is recommended. There is an increased risk of iatrogenic instability in this patient population due to the inability of an arthroscopic procedure to correct the structural instability inherent to this population.[9,30,70,73]

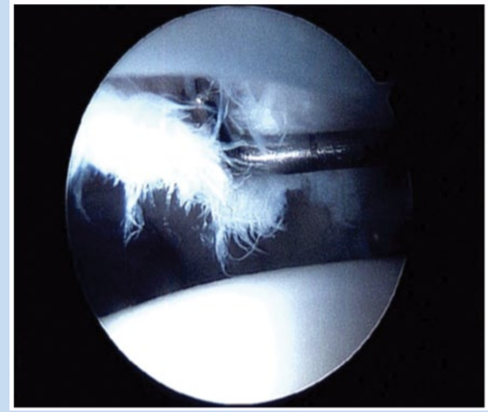

Figure 14. Intraoperative image demonstrating labral-chondral injury treated arthroscopically during combined arthroscopic and open hip preservation surgery.

Formerly, PAO was performed as an index procedure in isolation, with successful outcomes at short- and mid-term assessments.[61] Unsatisfactory long-term results have been reported,[65] with rates of conversion to total hip arthroplasty as high as 17%.[21,74] In the setting of acetabular undercoverage, the labrum and ligamentum teres often undergo hypertrophy to compensate for a lack of containment and stability of the femoral head.[87] Consequently, the labral-chondral transitional zone and ligamentum teres are often damaged as the result of focal edge-loading and increased shear force across the weightbearing surface of the acetabulum.

The use of adjuvant hip arthroscopy to address intra-articular hip disease with large-scale open structural correction offers potential benefits and strengths of both procedures and may further optimize clinical outcomes at mid- and long-term follow-up.[85]

CONCLUSION

A comprehensive understanding of the relationship between femoral and pelvic orientation, morphology, and the development of intra-articular abnormalities is necessary to formulate an effective and patient-specific treatment strategy that has the potential to produce a favorable and durable outcome for the patient.

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