Imaging in Hip Arthroscopy for Femoroacetabular Impingement

A Comprehensive Approach

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KEYWORDS

• Hip arthroscopy • Femoroacetabular impingement • Imaging • MRI • MRA
• Hip capsule • CT • Revision hip arthroscopy

KEY POINTS

- Plain radiographs, including anteroposterior pelvis, Dunn lateral, and false-profile view, are key in initial assessment of patients suspected of femoroacetabular impingement.
- Computed tomography scans rely less patient positioning and allow for accurate definition of the exact location and size of pincer-type and cam-type deformities, and can be particularly helpful in revision hip arthroscopy.
- Studies have shown high incidence of labral tears in asymptomatic patients, thus correlation between clinical and imaging findings is stressed.
- Systematic implementation of intraoperative fluoroscopy can assist in providing adequate acetabular and femoral decompression and avoid the most common cause of revision hip arthroscopy.

INTRODUCTION

The role of diagnostic imaging in femoroacetabular impingement (FAI) is to complement the clinical presentation and findings on physical examination. Diagnostic imaging provides objective information to the clinician, separate from confounding

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variables and unclear history. This can support or negate FAI among competing diagnoses. That said, abnormal femoral morphology and other findings consistent with FAI alone are not diagnostic for FAI if the corresponding clinical findings and/or symptoms are absent.[1] As a result, during initial work-up and preoperative planning, it is critical to choose the right diagnostic studies to answer the clinical questions at hand.

This article provides a comprehensive approach to imaging in FAI, from initial office-based radiographs to advanced preoperative 3-dimensional (3D) imaging. At any point imaging is used, it is important to evaluate the whole picture and consider pelvic joint abnormalities and muscular injuries that may mimic the symptoms or findings of FAI.

PLAIN RADIOGRAPHY

Plain radiographs play a key role in initial management of patients presenting with hip pain when FAI is suspected. Several options exist regarding views and these should be fully understood to optimize information obtained. From these radiographs, several parameters can be obtained to help evaluate patients before hip preservation surgery. These same radiographs can be helpful when considering revision hip arthroscopy and postoperative correction of deformity.

Anteroposterior (AP) pelvis radiograph is obtained routinely with patients positioned supine with the legs internally rotated by 15°. To allow optimal evaluation, the radiograph beam should be centered between the pubic symphysis and the anterior superior iliac spine.[2] AP pelvis radiographs are particularly useful for identification of the presence of osteoarthritis and measurement of joint space remaining to classify the degree of joint space loss. The Tönnis grade can be helpful to quantify the amount of joint space narrowing.[3] Patients with Tönnis grade 2 or more generally benefit less from hip preservation.[2] Several important radiographic parameters allow for detailed analysis of morphology on both the acetabular and femoral sides. These parameters should take into account the relative tilt of the pelvis and rotation by evaluating symmetry and bony relationships because this has a profound influence on acetabular version.[4]

Pincer-type FAI is appreciated on the AP radiograph by presence of acetabular retroversion, overcoverage, coxa profunda, protrusio acetabula, and increased anterior center-edge angle or lateral center-edge angle (LCEA).[5] Measurement of the lateral and anterior center-edge angle are helpful screening measures in most cases; however, there are abnormal acetabular morphologic variants that may not always be defined by these parameters. Measuring the LCEA and acetabular inclination angle (Tönnis angle) are measurements that can characterize acetabular morphology. Global overcoverage has been defined as an LCEA greater than 40° and Tönnis angle less than 0° (**Fig. 1**). Acetabular dysplasia can be defined by LCEA less than 20° and Tönnis angle greater than 10°. There are other radiographic findings that may be relevant, such as Shenton line, femoral version, and neck shaft angle.

Coxa profunda is now recognized as potentially a normal variant in many individuals.[6,7] Evaluation for acetabular dysplasia is crucial to successful patient selection.[8] When the center of the femoral head extends beyond the ilioischial line, acetabular protrusio may be present, representing global overcoverage of the femoral head.[9–11] Presuming a proper pelvic tilt on AP pelvic radiograph, a crossover sign denotes that the anterior wall of the acetabulum projects lateral to the posterior wall before converging at the lateral acetabular sourcil. Once a crossover sign is recognized, quantification can be achieved by measuring the retroversion index, which can be helpful in planning surgical correction.[10,12] A posterior wall sign indicates that the center of the femoral head projects lateral to the posterior wall, which is another sign of true

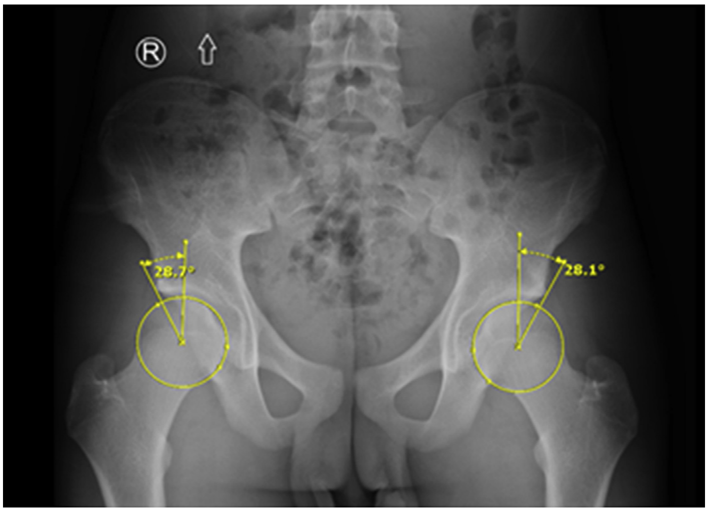

Fig. 1. AP pelvis radiograph demonstrating measurement of bi-LCEA in 16-year old male patient with FAI.

acetabular retroversion.[2] Although a posterior wall sign represents true acetabular retroversion, an isolated crossover sign may represent focal overcoverage by the anterior wall in pincer-type deformity.

Proximal femoral pathoanatomy is a 3D deformity that may be easily identified on plain radiographs in moderate to severe cases or, in subtle cases, may only be obvious on arthroscopic visualization. The alpha angle represents the most commonly used parameter (**Fig. 2**) with the alpha point representing where the deformity extends outside the best-fit circle.[13,14] In Notzli's original work,[15] symptomatic patients had

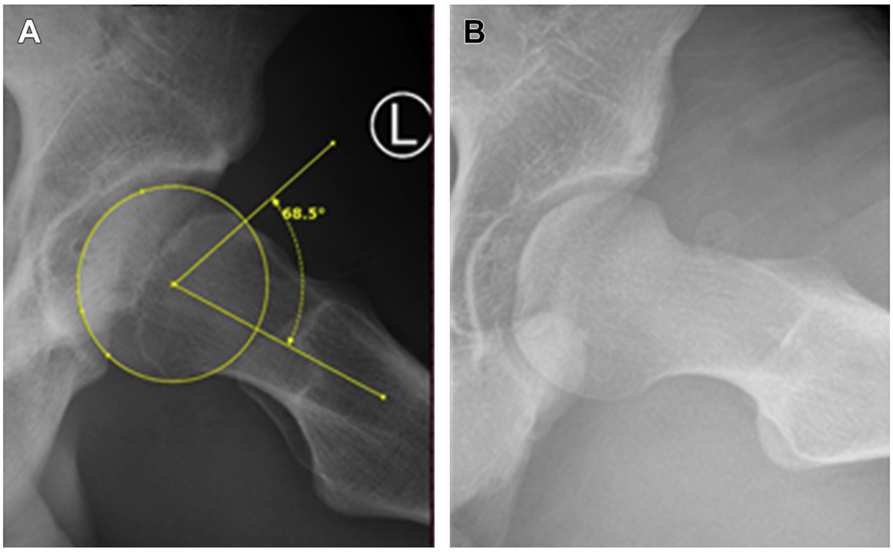

Fig. 2. Modified Dunn lateral view of left hip in 16-year-old male patient with cam deformity. (*A*) Alpha angle. (*B*) Modified Dunn lateral after cam resection.

an alpha angle averaging 74° compared with 42° in asymptomatic patients. Several other studies reported other ranges of normal.[9,15] Most orthopedic surgeons define a cam deformity as greater than 50° on any radiographic view. In some cases, the cam deformity is best appreciated on the AP view known as a pistol grip deformity.[16,17] The measurement of the alpha angle on the AP view is also known as the gamma angle. Further analysis can include quantitative complementary measurement of the patient's cam-type deformity and head neck offset.[2]

The authors recommend using a series of plain radiographs to visualize the proximal femoral anatomy in different positions. Each radiographic view needs to be scrutinized to identify an abnormal head neck offset. The authors' institutional preference is to use a combination of the AP pelvis, false-profile, and 90° Dunn lateral view; each of these can be used to measure cam morphology. In addition to characterizing the femoral head-neck junction, the false-profile view may be obtained to evaluate several parameters, including the morphology of the anterior inferior iliac spine.[18] Several variations of the lateral femoral view exist, including the 45° and 90° Dunn lateral, cross table lateral, and frog leg lateral. Other notable findings in symptomatic patients on plain radiographs may include impingement cysts and trough signs.

The importance of correlating radiographic findings to clinical symptoms cannot be overemphasized because a large portion of patients with FAI morphology may never become symptomatic. The literature suggests a high number of asymptomatic patients have radiographic measurements indicating FAI.[6,7]

COMPUTED TOMOGRAPHY

3D imaging allows for advanced characterization of the patient's bony morphology. Computed tomography (CT) can be profoundly helpful in surgical planning for FAI.[3,19] Advances in preoperative planning software and motion analysis technology based on advanced imaging represent a growing area of hip preservation surgery.[19,20] CT is helpful in further delineation of a bony pathologic state noted on plain radiographs, though routine use is controversial given the degree of radiation exposure.[21] This is a particularly important consideration in young patients who are being considered for FAI surgery.[3]

Acetabular version and pincer morphology can be appreciated at a high level on multiplanar or 3D CT reconstructions (**Fig. 3**).[22] When considering hip arthroscopy

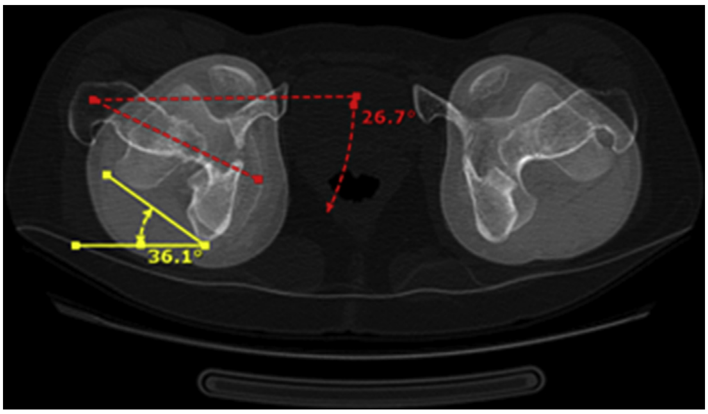

Fig. 3. CT measurement of femoral anteversion is performed by measuring the angle formed between the long axis of the femoral neck and a line parallel to the dorsal aspect of the femoral condyles on axial CT scan.

with femoral osteochondroplasty, the exact location of cam deformity can be determined with CT.[23] The CT scan can also obtain information about the proximal femoral version to characterize extra-articular deformity and impingement. 3D reconstructions can be rendered to allow for detailed assessment of areas of impingement, especially in the revision situation (**Fig. 4**).[24,25] Finally, when MRI is contraindicated, CT arthrography may represent an alternative to MRI for evaluation of labral and soft tissue disease, though MRI remains the gold standard for chondrolabral injury.

MAGNETIC RESONANCE IMAGING

MRI is a common diagnostic option to evaluate soft tissue hip injuries in patients undergoing workup for FAI. Imaging techniques include but are not limited to conventional noncontrast MRI, indirect magnetic resonance arthrography (MRA) and direct MRA. The latter techniques differ by route of contrast injection. Indirect MRA is intravenously injected; direct MRA is intra-articularly injected.[2] Routine imaging sequences include coronal fat-saturated T2 fast spin echo (FSE), coronal T1 FSE, sagittal proton density (PD) FSE, axial PD FSE, and FS axial oblique PD FSE, and radial PD FSE.[26,27] These multiplanar sequences and the excellent tissue contrast resolution of MRI or MRA demonstrates intra-articular soft tissue disease commonly seen with FAI, such as the acetabular labrum and articular cartilage. They also reveal extra-articular disease such as hip abductor tendinopathy or trochanteric inflammation associated with FAI.[28–32] In addition to soft tissue structures, MRI can be used to identify osseous pathomorphology, such as cam deformities, through radial or axial oblique slices, acetabular anteroversion or retroversion, femoral head-neck offset, and femoral antetorsion. MRI is unique for the ability to demonstrate bone marrow edema or subchondral cysts before radiographic changes are seen.[26,27,33,34]

Evaluating for labral tears is an important diagnostic step in the work-up of FAI.[35] Several studies[36–38] have demonstrated that direct MRA increases sensitivity for assessing labral pathomorphology. Intra-articularly injected contrast distends the hip joint and promotes separation of the labrum from the hip capsule, thus enhancing visualization of labrum and associated disease.[39] The 2 prominent findings of labral tears are (1) contrast extending into the body of the labrum and (2) labral detachment from the acetabulum (**Fig. 5**). Although useful at categorizing different types of labral tears, Blankenbaker and colleagues[40] found poor correlation between the original

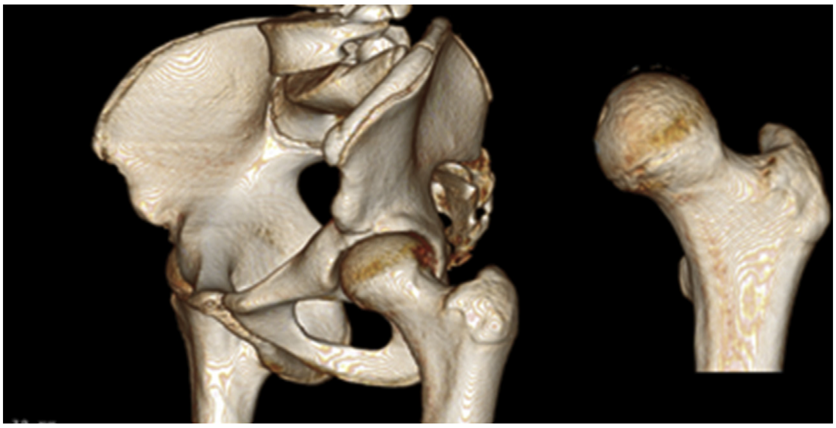

Fig. 4. 3D reconstructions demonstrating cam deformity in a 16-year-old ballet dancer.

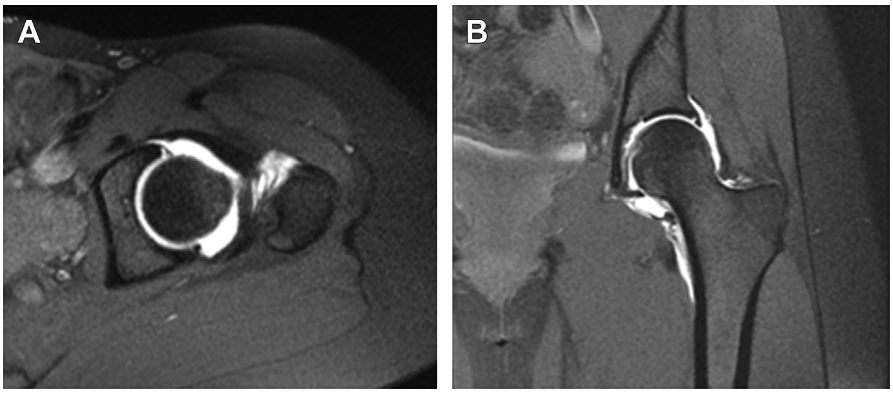

Fig. 5. Axial (*A*) and coronal (*B*) MRI arthrogram images demonstrating an anterolateral labral tear of the left hip.

classification by Czerny and colleagues[41] and the Lage arthroscopic classification system.[42] The latter is performed intra-operatively and segregates labral tears into radial flap tears, radial fibrillated tears, longitudinal peripheral tears, or unstable tears.[29,40,42] To address this, Blankenbaker and colleagues[40] proposed a descriptive system in which labral tears were divided into frayed, flap, peripheral longitudinal, and unstable. Location and extent of tears in this study[40] were determined using the clock-face localization system. In their study of 65 hip MRAs, Blankenbaker and colleagues[40] found 54% of labral tears isolated between the anterosuperior 12 to 3 o'clock position, with an additional 40% of tears involving this region but extending outside of it.[40]

Although MRA has shown to have high sensitivity for identifying labral disease, normal morphologic variants exist that can potentially obscure the workup of hip pain and FAI.[43] In a study of 200 asymptomatic subjects, Lecouvet and colleagues[43] found heterogeneity in both labral shape (66% triangular, 11% round, 9% flat) and signal intensity. Paralabral sulci and acetabular clefts have also been described as normal variants and are not to be confused with labral detachments or tears.[44] The incidence of sublabral sulci is roughly 20%.[45,46] They can be distinguished from tears by the relatively decreased depth, less signal intensity, and an absence of paralabral cysts or cartilage damage.[27,39,45,46] Just as important is that abnormal findings can be present in asymptomatic individuals. In a recent study of 45 asymptomatic hips, Register and colleagues[1] identified labral tears in 69%, chondral defects in 24%, and paralabral cysts in 13%.[1] Further, the incidence of labral tears in the asymptomatic population has been reported as high as 83% in 1 cohort.[47] Thus, when assessing labral morphology, correlation between clinical and imaging findings must be stressed.

Cartilage damage is also frequent in FAI and, until recently, MRI had less diagnostic usefulness for evaluating chondral lesions. Traditional MRI of the hip articular cartilage is impeded by limited cartilage thickness, its complex 3D geometry, and the close apposition between the femoral head and acetabular cartilage layers.[48] In comparison to the greater than 90% sensitivity of MRA in detecting labral tears, Anderson and colleagues[49] report a 22% sensitivity for MRA to detect cartilage delamination. Pfirrman and colleagues[30] report a similarly low sensitivity (26%) when using hyperintense fluid signal beneath the cartilage to define delamination but a higher sensitivity (63%, with 90% specificity) when defining delamination by hypointense areas in the acetabular cartilage on coronal intermediate weighted fat-saturated images. Despite improvements in imaging protocol and technique, the ability of conventional MRI or MRA to detect cartilage pathomorphology in the hip remains limited to identifying gross lesions.[27]

ROLE OF IMAGING IN PREOPERATIVE PLANNING

Following an appropriate and thorough history and physical examination, diagnostic imaging plays an important role in determining the correct diagnosis for the young patient with hip pain.[50] Recognition and correlation of physical examination findings with bony and soft tissue abnormalities identified on diagnostic imaging allows the surgeon to appreciate the unique fingerprint of disease in each patient. Preoperatively identifying the individualized pathologic condition helps to devise a preoperative plan for adequate treatment. This section outlines the standard preoperative imaging assessment implemented by the senior author (SJN).

The imaging assessment of every patient that presents with hip or groin pain begins with plain radiographs. Standardized radiographs are mandatory and care is taken to ensure correct film-focus distance and proper centering of the radiograph beam to prevent alteration of the osseous anatomy and thus false impressions.[3,51]

The senior author's preferred initial radiographs include a true AP radiograph of the pelvis and 2 lateral views of the affected hip. The lateral views include a 90° Dunn lateral and a false-profile lateral. The AP of the pelvis is used to evaluate the focal and global overcoverage of the hip joint, as well as the acetabular rim morphology.[51] In addition, the AP pelvis and false-profile views can be used to determine if there are signs of hip dysplasia. The false-profile view is valuable to gain information regarding the magnitude of anterior acetabular coverage in addition to denoting any signs of potential subspine impingement.[52,53] The assessment of the proximal femur is conducted on the AP pelvis (assessing the most lateral aspect of any cam morphology) and on the 2 lateral views (assessing increasingly more anterior aspects of any cam morphology).[15] The false-profile view has been most strongly correlated to characterization of cam deformity at the 2 o'clock and 3 o'clock positions on CT scan.[18] The false-profile view combined with AP pelvis and 90 Dunn lateral view of the hip comprise a good screening radiographic series for patients presenting with symptoms of FAI. In addition to calculating an alpha angle, the head-neck offset and femoral neck-shaft angle can calculated.[3]

In young, active patients with symptomatic FAI determined by initial radiographs, the authors use advanced imaging modalities to preoperatively plan the osseous resection and concomitant soft tissue procedures. We currently use CT scanning of the hip to obtain a 3D representation of the osseous morphology of the proximal femur and acetabulum independent of patient positioning. A benefit of CT compared with plain radiographs is the ability to more accurately measure the degree of focal or global acetabular coverage.[4,54] On the femoral-side, we use CT to further characterize the 3D morphology of the cam deformity. CT has been shown to improve surgeons' intraobserver and interobserver reliability of measurable FAI parameters compared with plain radiographs.[22,55] MRI is also routinely used in preoperative planning. With proper sequencing techniques, noncontrast MRI is comparable to MRA and without the additional invasiveness and cost.[56] At the authors' institution, MRA is the preferred method to evaluate for the intra-articular soft tissue structures of the hip. This modality is used to identify labral tears, chondral delamination and degeneration, capsular deficiency (**Fig. 6**), and other soft tissue abnormalities that can be addressed at the time of surgery.[57]

Finally, in symptomatic patients with either multiple possible sources of pain or in patients where the diagnosis is unclear, image-guided injections can be used for

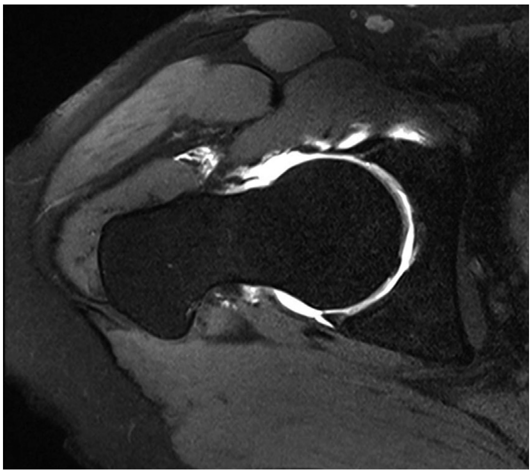

Fig. 6. Axial MRI arthrogram in a 36-year-old female patient with microinstability and persistent pain after a previous hip arthroscopy. MRI demonstrates contrast extravasation and a persistent capsular defect.

both diagnostic and therapeutic purposes. Compared with blind injections, image-guided injections are safer, more accurate, and result in better clinical outcomes.[58] Relief of pain after an intra-articular injection is 90% reliable as an indicator for intra-articular hip pathologic condition and may predict improved outcomes following surgery.[59,60] The authors' preferred injection procedure is to perform an examination of the patient before the injection, and repeat the examination after the injection to quantify the extent of relief.

IMAGING PARAMETERS OF SUCCESSFUL FEMOROACETABULAR IMPINGEMENT CORRECTION

Incomplete resection of underlying FAI deformity is a major reason for residual hip pain following surgery and a leading cause of revision hip arthroscopy.[24,25,61–64] Over-resection of offending osseous disease may lead to iatrogenic instability and poor outcomes.[61,65,66] In addition to careful attention to preoperative imaging, recent research has suggested that systematic implementation of intraoperative fluoroscopy can assist in providing adequate acetabular and femoral decompression and avoid the most common cause of revision hip arthroscopy.[23,67–69]

When addressing the acetabular correction of pincer-type FAI, recent research has demonstrated that small resections on the order of 5 to 10 mm make large changes in center-edge angle measurements.[67,68,70] Kling and colleagues[67] concluded that a 1 mm resection will decrease the LCEA by 1° and the anterior center-edge angle by 2°. This formula may be used intra-operatively to balance the line between adequate rim resection and iatrogenic instability. The authors also use the anterior margin ratio to quantify the amount of acetabular overcoverage on intra-operative fluoroscopy to guide the amount of rim resection. Similarly, intraoperative techniques exist to ensure adequate femoral-sided decompression. Ross and colleagues[23] implemented an accurate and reproducible approach to obtain 6 fluoroscopic views to confirm complete cam resection. Each of the 6 intraoperative fluoroscopic views corresponds to a standardized right hip clock-face position, which is the most common nomenclature for discussing FAI position.[21,71,72] The femoral head-neck region covered by the

6 radiographic views (11:45–2:45) has been documented as the region most commonly associated with cam pathologic condition.[33,57,64,73] In similar fashion to acetabular-sided decompression, intraoperative use of fluoroscopy on the femoral side aids in balancing the fine line between under-resection, leading to residual pain, and over-resection, leading to femoral neck fracture.[24,25,61–64,74,75]

FUTURE DIRECTIONS

Cartilage disease may be predictive of poorer outcomes after hip preservation surgery. Despite the limitations of conventional MRI, recent advances in biochemical imaging techniques have shown promise for detecting cartilage disease earlier and on a microscopic level.[76–79] These techniques include quantitative T2 and T2* relaxation mapping to assess cartilage water content and collagen organization,[77,80] as well as T1rho (T1ρ)[78] and delayed gadolinium-enhanced MRI of cartilage (dGEMRIC)[81] techniques to evaluate proteoglycan content. dGEMRIC studies require injection of a negatively charged gadolinium contrast agent, which distributes according to the negative charge of extracellular glycosaminoglycans. Areas of diseased cartilage with lower proteoglycan content (and higher water content) will, therefore, have higher amounts of contrast and shorter $T1_{Gd}$ relaxation time (**Fig. 7**).[82] dGEMRIC is capable of detecting cartilage damage in patients with FAI,[81,83] as well as in asymptomatic patients with cam deformities.[84] When injected intra-articularly, it can combine the advantages of dGEMRIC for cartilage assessment with arthrography for labral evaluation.[85]

T1ρ imaging techniques also assess the relative glycosaminoglycan of hyaline cartilage but do not require the contrast injection. Despite a paucity in the literature on this topic, available studies suggest that T1ρ can detect articular cartilage abnormalities in patients with FAI, as well as in asymptomatic patients with cam deformities.[78,86,87] Although promising, preliminary imaging studies require replication and standardization to increase the applicability of these developing techniques.[79]

Patient-specific 3D models of the hip using commercially available 3D CT rendering software have been developed and may allow clinicians to perform dynamic analysis of the hip. This analysis has been used to identify mechanical impingement in a patient's range of motion, including sports-specific positions, which may then be used

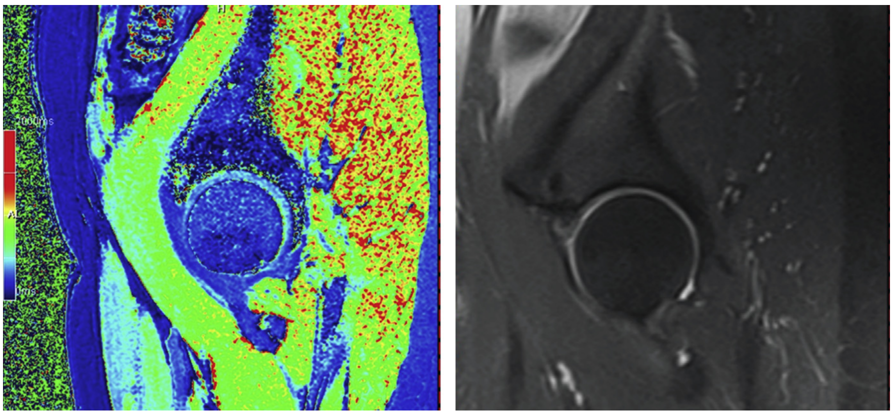

Fig. 7. dGEMRIC (*left*) and sagittal T2 weighted MRI images (*right*) demonstrating well-preserved cartilage in a 36-year-old patient being considered for revision hip arthroscopy.

in a preoperative plan to plan the bony resection. Many investigators suggest this type of individualized plan of care is the way of the future because it may increase precision and decrease radiation.

SUMMARY

Hip arthroscopy continues to experience incredible growth and advances in imaging have progressed concomitantly. Plain radiographs play a key role in initial management of patients presenting with hip pain when FAI is suspected. 3D imaging with CT and MRI allows for advanced characterization of the patient's bony morphology and soft tissue injury. Incomplete resection of underlying FAI deformity is a major reason for residual hip pain following surgery and a leading cause of revision hip arthroscopy. A comprehensive approach to preoperative and intraoperative assessment of FAI treatment portends the best outcome.

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