Technical Note

Comprehensive Clinical Evaluation of Femoroacetabular Impingement: Part 3, Magnetic Resonance Imaging

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Abstract: Radiologic imaging is an essential supplement to the physical examination in the evaluation of a patient with femoroacetabular impingement. Plain radiographs are the initial modality of choice for the evaluation of bony anatomy and pathology. Magnetic resonance imaging supplements the physical examination and standard radiographs by enabling qualitative and quantitative evaluation of both articular cartilage and soft tissues about the hip. Magnetic resonance imaging also provides improved 3-dimensional characterization of the bony anatomy owing to the multiplanar nature of this technique. This article describes a comprehensive approach to interpretation of magnetic resonance examination of the hip.

Imaging evaluation of the hip supplements a thorough physical examination in patients with hip pathology. Plain radiographs allow identification of bony pathology such as classic femoroacetabular impingement (FAI) findings including cam deformities, pincer lesions, and anterior inferior iliac spine impingement. Radiographs also allow for objective evaluation of neck-shaft angle abnormalities, acetabular morphology, femoral head asphericity, avascular necrosis, traumatic injury, joint space narrowing, and subchondral cysts. Whereas magnetic resonance imaging (MRI) also facilitates characterization of these bony lesions, it is uniquely capable of evaluating the labrum, cartilage, ligamentum teres, synovial tissue, capsule, and adjacent muscles and tendons.

It is important to note that a 25-fold increase in hip arthroscopy volume between 2006 and 2013 was reported.1 As hip arthroscopy continues to grow as a discipline, the further incorporation of sophisticated imaging into clinical practice is expected. An orthopaedic surgeon should be adept at selecting the appropriate imaging modality to evaluate hip pathology, as well as interpreting the radiographic findings. However, partnership with a designated musculoskeletal radiologist is paramount, especially when reviewing advanced MRI techniques. This article is part 3 of a 3-part series; part 1 addressed the physical examination,2 and part 2 addressed interpretation of plain radiographs.3 The purpose of this technical note is to describe a comprehensive approach to interpretation of hip MRI for the orthopaedic surgeon. A description of an example MRI protocol is included, along with a discussion of the optimal sequences and planes for identifying key pathology and quantifying bony morphology.

MRI Technique

Most institutions have a standard set of imaging planes and sequences for each imaging modality and indication, and the referring clinician should have a...
familiarity with the protocols. Specifically, hip MRI protocols comprise several imaging planes including an oblique plane along the femoral neck (to measure the alpha angle), as well as standard coronal, sagittal, and axial planes. Certain tissue weightings including T1, T2, and proton density (PD) may be obtained, and compositional cartilage imaging techniques may be performed. Often, the contralateral hip is included in the coronal series to allow comparison of marrow characteristics.

Table 1. Commonly Obtained Hip MRI Planes and Sequences

<table>
<thead>
<tr>
<th>Technique</th>
<th>Imaging Plane</th>
<th>Sequence</th>
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<tbody>
<tr>
<td>1</td>
<td>Axial</td>
<td>T2 TSE</td>
</tr>
<tr>
<td>2</td>
<td>Axial oblique</td>
<td>PD FS</td>
</tr>
<tr>
<td>3</td>
<td>Axial (knee)*</td>
<td>T1 TSE</td>
</tr>
<tr>
<td>4</td>
<td>Sagittal</td>
<td>PD TSE FS</td>
</tr>
<tr>
<td>5</td>
<td>Sagittal</td>
<td>PD</td>
</tr>
<tr>
<td>6</td>
<td>Sagittal</td>
<td>T2 mapping</td>
</tr>
<tr>
<td>7</td>
<td>Coronal</td>
<td>PD TSE</td>
</tr>
<tr>
<td>8</td>
<td>Coronal</td>
<td>PD TSE FS</td>
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FS, fat suppressed; MRI, magnetic resonance imaging; PD, proton density; TSE, turbo spin echo.

* Axial scout images are obtained at the knee to allow measurement of femoral neck version.

Fig 1. The lateral center-edge angle (LCEA) quantifies the amount of lateral overhang of the acetabulum. Measurement of the LCEA is shown in this right hip coronal proton density turbo spin echo fat-suppressed magnetic resonance image. An angle is made between the longitudinal pelvic axis, the center of the circle (the apex), and the lateral aspect of the acetabulum. The reported normal range is 25° to 40°, less than 20° is considered dysplastic, 20° to 25° is considered borderline dysplastic, and greater than 40° may be associated with a pincer lesion. The LCEA in this patient is 34° and considered to be within the normal range.

Fig 2. Measurement of the alpha angle allows quantification of the size of a cam deformity due to femoral head-neck offset abnormality. The technique for measurement of the alpha angle is shown in this right hip axial oblique proton density fat-suppressed magnetic resonance image. A best-fit circle is placed at the femoral head and preferentially aligned with the anterosuperior region. A second best-fit circle can be placed at the narrowest aspect of the femoral neck to allow localization of the neck axis. An angle is then drawn between the center of the femoral neck, the center of the femoral head (i.e., the apex of the angle), and the location where the femoral head extends beyond the boundary of the best-fit circle (i.e., becomes out of round).

Fig 3. Fluid-sensitive sequences with axial oblique sections are optimal for identification of labral tears, although coronal sections may also be used. An anterosuperior labral tear (arrow) is shown in this right hip axial oblique proton density (PD) fat-suppressed (FS) magnetic resonance image. To better understand the 3-dimensional pattern of the tear, multiple imaging planes and sequences should be evaluated, including coronal PD turbo spin echo FS, axial T2 turbo spin echo, and axial oblique PD FS.
Some surgeons and radiologists request the injection of intra-articular contrast for more detailed evaluation of the labrum and cartilage. However, most historical studies comparing hip MRI with and without intra-articular contrast were performed on 1.5-T platforms and may not be comparable to optimized, high-resolution, nonarthrographic 3-T MRI. A recent study in patients with clinically suspected FAI reported that nonarthrographic 3-T MRI was highly accurate for evaluating the labrum and cartilage. When combined with clinical history, physical examination, and plain radiography, high-resolution 3-T MRI allows avoidance of the need for intra-articular contrast. A standardized nonarthrographic hip MRI protocol is outlined in Table 1.

Comprehensive Interpretation of Hip MRI

Bone Morphologic Characteristics

MRI is optimized for soft-tissue characterization, and detailed evaluation of cortical bone is limited because of low relative proton density. Despite this limitation, cortical bone is sufficiently imaged on MRI and does not expose the patient to ionizing radiation, and quantitative analysis of bony morphology is allowed. However, there has been a trend toward use of computed tomography imaging to assist with surgical planning for FAI because of improved cortical bone imaging. Although computed tomography may be optimized for cortical bone imaging, quantitative analysis of bony morphology is feasible on MRI.

Acetabular morphology is quantitatively described by measurement of the amount of femoral head coverage using the lateral center-edge angle. By use of the coronal sequences, a best-fit circle is drawn to identify the center of the femoral head (Fig 1). An angle is made between the longitudinal pelvic axis, the center of the circle (the apex), and the lateral aspect of the acetabulum. The normal range is 25° to 40°, less than 20° is considered dysplastic, 20° to 25° is considered borderline dysplastic, and greater than 40° may be associated with a pincer lesion.

Femoral head asphericity is quantified with the use of the alpha angle, as described by Notzli et al., and is performed on the T2 axial oblique series (Fig 2). The alpha angle allows quantitative characterization of the deformity associated with cam-type FAI. A best-fit circle is placed at the femoral head and preferentially aligned with the anterosuperior region. A second best-fit circle is placed at the narrowest aspect of the femoral neck to

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**Table 2. Compositional Assessment of Articular Cartilage**

<table>
<thead>
<tr>
<th>MRI Technique</th>
<th>Molecular Component Assessed</th>
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<tbody>
<tr>
<td>T2 mapping</td>
<td>Water, collagen</td>
</tr>
<tr>
<td>T2* mapping</td>
<td>Water, collagen</td>
</tr>
<tr>
<td>T1ρ imaging</td>
<td>Collagen, GAGs</td>
</tr>
<tr>
<td>dGEMRIC</td>
<td>GAGs</td>
</tr>
<tr>
<td>Diffusion-weighted imaging</td>
<td>Collagen, GAGs</td>
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</table>

dGEMRIC, delayed gadolinium-enhanced magnetic resonance imaging of cartilage; GAGs, glycosaminoglycans; MRI, magnetic resonance imaging.
allow localization of the neck axis. An angle is then drawn between the center of the femoral neck, the center of the femoral head (i.e., the apex of the angle), and the location where the femoral head extends beyond the boundary of the best-fit circle (i.e., “becomes out of round”).

Notzli et al.\(^9\) reported that the mean alpha angle was 42° in asymptomatic control subjects and 74° in the symptomatic group; greater than 50° was considered large.\(^{10,14}\) However, a higher threshold has also been suggested.\(^{13,14}\) Nonetheless, it is important to consider that an abnormal femoral head-neck offset, characterized by an increased alpha angle, is a 3-dimensional (3D) anatomic entity, and variable measurements may be obtained in the same patient with different imaging planes and by different reviewers.\(^{14}\)

Femoral neck version is measured by referencing the posterior condylar axis on an axial scout image of the distal femur.\(^{15}\) It has been suggested that femoral neck version may have implications for treatment of iliopsoas pathology. Fibrozystic changes, also known as impingement cysts, may be identified on both radiographs and MRI at the femoral head-neck junction.\(^{16}\) These lesions are typically located at the anterosuperior femoral neck in the region of impingement; at the time of surgery, they are often included in the osteochondroplasty.\(^{17}\) Large cysts may require grafting and can be filled with a biocomposite surgical screw.

**Labrum**

There is growing interest in the diagnosis and treatment of chondrolabral lesions, largely because of the increasing technical ability of treating FAI with hip arthroscopy. Despite advances in MRI hardware and

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**Fig 6.** Fluid-sensitive magnetic resonance (MR) imaging sequences are optimal for identification of subchondral cysts and bony edema. (A) An acetabular subchondral cyst with overlying chondromalacia is shown in this right hip sagittal proton density (PD) fat-suppressed (FS) MR image. (B) A femoral head subchondral cyst with overlying chondromalacia is shown in this right hip coronal PD turbo spin echo FS MR image. (C) Bone marrow edema in the femoral head with overlying chondromalacia is shown in this right hip axial oblique PD FS MR image.

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**Fig 7.** Tendinopathy is optimally identified on fluid-sensitive sequences and may be seen on coronal, sagittal, and axial sections. Left hip axial T2 turbo spin echo (A) and coronal proton density turbo spin echo fat-suppressed (B) magnetic resonance images show severe hamstring tendinosis in a professional female runner with femoroacetabular impingement.
acquisition techniques that result in higher-resolution magnetic resonance (MR) images with improved signal-to-noise ratios, imaging of the articular cartilage and the labrum in the hip remains challenging. Labral tears and/or detachment may be identified on coronal, sagittal, and axial oblique images (Fig 3).

Although the most common location for labral pathology is the anterosuperior region, the labrum is evaluated circumferentially using several imaging sequences. Tear location is referenced using the clock face with the “psoas-u” located at the 3-o’clock position anteriorly.18,19

Pulse sequences with high in-plane resolution such as T1 fat-suppressed (FS), T2 FS, and 3D water excitation dual echo steady state (DESS) are most sensitive for labral evaluation.4 Studies have reported a sensitivity and specificity of 80% to 97% and 85% to 100%, respectively, using T1 FS and T2 FS, with arthroscopy as the reference standard. Notably, 1 study using 3D DESS reported a sensitivity of 85% to 89% and a much wider specificity range of 50% to 100%.4 Particularly, higher field strengths (3.0 T vs 1.5 T), small fields of view, and external small surface coils (as opposed to coils housed within the table) are nearly essential when imaging the labrum. Data regarding the use of high-resolution unenhanced 3-T MRI of the hip are limited, and further study comparing 3-T MRI and MR arthrography is a major requirement for validating the use of unenhanced 3-T MRI.

As the frequency of hip arthroscopic procedures increases,1 so does the frequency of revision hip arthroscopy. Increased complexity is associated with these procedures, which may include labral reconstruction or labral augmentation for labral deficiency (Fig 4) or insertion of a capsulolabral spacer in the setting of capsulolabral adhesions (Fig 5).

Cartilage

The sensitivity of MRI and MR arthrography is limited in the morphologic evaluation of cartilage abnormalities of the hip, but specificity is typically high. This challenge gave rise to the use of compositional cartilage imaging.

Morphologic evaluation of cartilage refers to the assessment of its 3D structure, which is notably difficult with MRI because of the comparatively low-resolution imaging on a spheroid such as the femoral head. As in the case of labral evaluation, higher field strengths, small fields of view, and external small surface coils are vastly superior. The most well-studied sequence used for morphologic evaluation of cartilage is 3D DESS; however, T2 FS and PD (also called intermediate weighted) FS can also be used.4

Compositional assessment of cartilage is used to evaluate the molecular status of the fluid-filled collagen and proteoglycan network comprising hyaline cartilage. Post-acquisition processing then creates a color-coded map of the biochemical composition of the cartilage surface. Compositional techniques are being used more commonly in imaging articular surfaces,20 but they require greater technical expertise and are not yet widely used. A list of cartilage mapping techniques that the orthopaedic surgeon may encounter, as well as the molecular components the techniques assess, are presented in Table 2. T2 mapping is routinely used for hip imaging at our institution.

Ho et al.21 recently reported the results of a prospective study of T2 mapping in patients with FAI. Areas of damaged and healthy-appearing cartilage underwent intraoperative International Cartilage Repair Society grading followed by biopsy with subsequent histologic analysis. Increased T2 values were observed among damaged specimens compared with healthy specimens, with the greatest differences observed among specimens with mild degeneration, suggesting a role of T2 mapping for early detection of chondral lesions in the absence of gross morphologic changes.

Subchondral Changes

Subchondral cysts and bone marrow edema not identified on radiographs are readily identified on fluid-sensitive MRI (e.g., coronal PD turbo spin echo FS). It is important to scrutinize images for these findings because subchondral cysts are associated with full-thickness cartilage lesion as well as inferior outcomes.
in age- and activity-matched control subjects. Given the present challenges of morphologically evaluating a curved surface on MRI, subchondral cysts are a very useful secondary finding for cartilage injury. Soft-tissue (paralabral) cysts may be identified adjacent to a labral tear and can be a useful secondary sign of labral pathology.

Fluid-sensitive sequences are the most sensitive acquisitions for detecting cysts. The use of fat suppression provides greater contrast between fat-containing bone marrow and adjacent fluid (Fig 6).

**Tendinopathy**

Injury to extra-articular hip structures has been associated with intra-articular pathology (FAI) as a result of compensatory changes in excursion and muscle firing. Hamstring tendinosis has been associated with intra-articular hip pathology and impingement, most commonly in female patients with acetabular pincer morphology. It may also be associated with or result from gluteus maximus dysfunction, leading to over-firing of the hamstring tendons (Fig 7). In addition, rectus femoris tendinosis has been described in association with FAI. Iliopsoas pathology has also been implicated in association with FAI, although the preferred treatment is evolving.

The most sensitive sequence for diagnosing tendinosis is a fluid-sensitive acquisition with fat suppression, such as T2 FS. Viewing this sequence on axial and sagittal sections facilitates optimal evaluation of the major tendons crossing the hip, including the hamstrings, rectus femoris, iliopsoas, and gluteus medius and minimus (although the hip abductors are also well visualized on coronal sections).

**Capsule**

On the basis of basic science and clinical evidence, there has been a trend toward routine capsular closure in hip arthroscopy. Not all hip arthroscopists close the capsule, and although a consensus on the topic is lacking, this may be a cause of iatrogenic instability. However, there is a relative paucity of literature on the topic of MRI evaluation of capsular integrity. It is our experience that MRI allows qualitative assessment of capsular integrity and assessment of capsular defects (Fig 8). Capsular reconstruction has been described for treatment of these defects.

**Benign and Malignant Tumors**

Benign and malignant pathology may also be identified incidentally on MRI. Table 3 lists the most common benign and malignant primary osseous tumors of the pelvis, as well as benign osseous lesions of the proximal femur, in order of decreasing frequency. The standard MRI protocol for hip evaluation in the sports medicine population is unlikely to include short tau inversion recovery, diffusion-weighted, or post–intravenous contrast imaging sequences. Thus,

<table>
<thead>
<tr>
<th>Pathology</th>
<th>Imaging Plane and Sequence</th>
<th>Finding</th>
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<tbody>
<tr>
<td>Labral tear</td>
<td>Axial T2 TSE</td>
<td>Linear signal irregularity</td>
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<tr>
<td></td>
<td>Axial oblique PD FS</td>
<td></td>
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<tr>
<td></td>
<td>Coronal PD TSE FS</td>
<td></td>
</tr>
<tr>
<td>Chondral lesion</td>
<td>Coronal PD TSE FS</td>
<td>Discontinuity in articular surface</td>
</tr>
<tr>
<td></td>
<td>Sagittal T2 mapping</td>
<td></td>
</tr>
<tr>
<td>Cam deformity</td>
<td>Axial oblique PD FS</td>
<td>Increased alpha angle</td>
</tr>
<tr>
<td>Lateral overcoverage</td>
<td>Coronal PD TSE</td>
<td>Increased LCEA</td>
</tr>
<tr>
<td>Subchondral cysts or edema</td>
<td>Coronal PD TSE FS</td>
<td>Cyst formation</td>
</tr>
<tr>
<td>Tendinosis of hamstring, rectus, or iliopsoas</td>
<td>Sagittal PD TSE FS</td>
<td>Increased fluid within tendon and/or partial tearing</td>
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<tr>
<td></td>
<td>Axial T2 TSE</td>
<td></td>
</tr>
<tr>
<td>Tendinosis of gluteus medius or minimus</td>
<td>Coronal PD TSE FS</td>
<td>Increased fluid within tendon and/or partial tearing</td>
</tr>
</tbody>
</table>

FAI, femoroacetabular impingement; FS, fat suppressed; LCEA, lateral center-edge angle; PD, proton density; TSE, turbo spin echo.
requiring the patient to return for further imaging will be necessary when the incidentally detected lesion cannot be definitively characterized as benign. Bloem and Reidtma comprehensively described these lesions along with a pictorial review. The potential for soft-tissue tumors as well as malignant bone tumors underscores the importance of careful evaluation of all series images, as well as partnership with a musculoskeletal radiologist.

**Comprehensive Evaluation**

With the increased understanding of prearthritic and early-arthritis hip pathology, interpretation of hip MRI is an important skill for the orthopaedic surgeon. Video 1 reviews a comprehensive and systematic approach for hip MRI evaluation. This knowledge includes an understanding of each sequence used in a standard hip MR protocol, as well as the anatomic abnormality for which each acquisition is optimized (Table 4). An understanding of the clinical indication for hip MRI is also important. Taken together, these abilities help establish the surgeon’s independence when reviewing a study while recommending the most appropriate diagnostic evaluation.

**Discussion**

This article details a systematic approach for interpretation of hip MRI for the orthopaedic surgeon. Combined with clinical evaluation and radiographic assessment, MRI improves the surgeon’s ability to render a more specific diagnosis of hip pathology, which ultimately aids in preoperative patient counseling and surgical planning. Although MRI is optimized for soft-tissue evaluation, characterization of bony anatomy is also enhanced with this multiplanar technique.

The ability to thoroughly evaluate labral and chondral pathology continues to advance. Debate as to the necessity of joint distention with paramagnetic contrast agents for the morphologic evaluation of chondral and labral lesions is ongoing, and larger-scale studies are necessary to evaluate comparable sensitivity of MRI for labral pathology in the presence and absence of intra-articular contrast. Improved identification of chondral and labral pathology is supported by searching for secondary signs of injury such as osseous and soft-tissue cystic lesions, respectively. These findings are most sensitively identified on T2 FS sequences.

Incidentally imaged osseous lesions in the pelvis and proximal femur require constant vigilance when reviewing these studies. As discussed, when a definitive benign characterization cannot be obtained, further imaging and possibly tissue sampling with biopsy by the treating orthopaedic oncologist may be required. As imaging techniques continue to advance, improved familiarity by the orthopaedic surgeon, along with musculoskeletal radiologist partnership, will lead to improved care for patients with hip pathology.

**References**