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Operative Techniques in
Orthopaedics

Hip Pathology Evaluation and Imaging

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Hip injuries are increasingly common in athletics. Historically, hip injury was associated with significant disability and inability to return to prior level of function. Advances over the past 2 decades have improved understanding of hip biomechanics, risk factors, and associated injury patterns. Accurate diagnosis is the first step to development of an effective treatment plan. Physical examination of the hip can be challenging because of overlap with nonmusculoskeletal sources of pelvic but also because of variable presentation of symptoms across patient populations. A systematic approach to physical exam progresses from standing/walking position to seated and supine. Key physical exam maneuvers can decipher between intra- vs extra-articular pathology. Advanced imaging studies can detect early stages of hip degeneration, cartilage, and labral disease. Plain radiographs remain an essential and efficient screening tool to assess patients presenting with hip injury or pain. The experienced clinician can use physical exam and imaging data to drive effective treatment and also predict the potential early and long-term outcome of surgical intervention.

KEYWORDS athletic hip pain, femoroacetabular impingement

Introduction

Accurate diagnosis and efficient management of hip injuries remains a challenge in sports medicine. The high demands required of the hip for athletic performance result in frequent injury, while the complex anatomy of the hip and core coupled with limited ability of patients to precisely and consistently describe their symptoms can create a diagnostic dilemma. Few hip injuries are straightforward. More frequently presenting complaints and pain will be variable in location and time within the same athlete. Advances in provocative exam maneuvers and diagnostic imaging technology over the past 15 years has resulted in significant improvement in diagnosis and in turn, helped to develop better treatment protocols. Hip arthroscopy is in its relative infancy compared to knee and shoulder arthroscopy. The first arthroscopic diagnosis of an acetabular labral tear was published in 1986[1] and high-volume hip arthroscopy evolved over the past 3 decades. Colvin et al reported an 18-fold increase in hip arthroscopy procedures performed in the United States from 1999 to 2009.[2] During this time, we have been able to more accurately correlate patient history, risk factors, injury pattern, physical exam findings, diagnostic imaging, and arthroscopic findings. Intermediate follow-up yields high rate of return to sports after arthroscopic management of femoroacetabular impingement (FAI) and labral tears. Long-term follow-up is required, but early results are promising for hip preservation in our patients.

Evaluation

History

Every patient encounter should begin with a thorough history of the patient's condition. Patients will typically focus primarily on recent events as the cause of their symptoms, but the history should begin with a discussion of any issues, injury, or treatments that may have occurred in infancy, childhood, or early adulthood. Hip stability is a broad spectrum from overt dysplasia, typically detected at birth or soon after, to severe FAI which may present with a lifetime of limited range of motion (ROM) or stiffness. Dysplasia, FAI, and other pediatric

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hip disorders (frequently slipped capital femoral epiphysis or Perthes disease) may have short lived presentation in childhood but, typically most patients will recall if they had any form of treatment. Involving parents when treating minors and young adults will garner more valuable information. All of these variable developmental states can alter hip mechanics or place abnormal stresses across the hip that will present as "injury" many years later. Effective treatment necessitates a complete understanding of possible contributing factors to hip injury whether muscular extra-articular injuries or intra-articular damage such as cartilage and labral injury. Once the remote history has been reviewed, a detailed account of the current presentation is obtained. The mechanism of injury, duration of symptoms, and location and intensity of pain can all help narrow what is typically a very broad differential. The complete hip and core history should include screening for potential gastrointestinal or genitourinary condition and resultant nonmuscular pelvic pain. Such conditions can be life-threatening and if questioning elicits suspicion, referral to a specialist should soon follow. Functional status and degree to which the patient is limited are assessed. In general, the treatment plan should match the degree of disability. Many patients will still perform at an extremely high level despite hip abnormality or injury while others may be completely unable to participate in their desired activities. The provider must understand the goals of the patient, assess the risk of further injury, and develop a comprehensive treatment plan. Patients will frequently describe mechanical symptoms such as a sense of instability, clicking, popping, snapping, or locking. These may be normal findings although they may become an area of athlete focus. They physician must determine if these symptoms are truly contributing to disability. Finally, a comprehensive inventory of all previous hip treatments and their efficacy should be undertaken. In the clinical setting, it is historically suggested that patients undergo diagnostic injection to "confirm" the diagnosis, but recently several authors have shown that diagnostic injection is of little predictive value in patients undergoing hip arthroscopy.[3,4] We do not believe it is absolutely necessary to have a confirmatory injection when all aspects of the history, physical examination, and imaging are in agreement with the diagnosis. However, a complete lack of response to a seemingly appropriate treatment or injection should always trigger a reassessment of the working diagnosis.

Physical Exam

Performing a comprehensive physical exam is a key step in guiding diagnosis of a patient's hip condition. Hip examination should follow the same principles as all common orthopaedic complaints; inspection, palpation, ROM, and finally, provocative maneuvers should be performed in a standardized fashion. Evaluation of the contralateral healthy limb allows the examiner to gain an appreciation for the patient's baseline condition and potential risk-inducing deficits in motion or strength. All exams should also incorporate standard screening evaluation of the lumbosacral spine and neurovascular testing of the distal extremities. For ease of discussion, the hip exam can be broken down based on patient position. The clinical hip exam will progress from a standing/walking position, to sitting and lying supine, lateral, and/or prone as a matter of routine practice.

Inspection

The patient should be closely observed in standing, sitting, and supine positions. First, resting stance is evaluated with attention to any potential malalignment of the axial skeleton that could contribute to abnormal stressors across the hip. Such conditions include limb length inequality, excessive pelvic tilt or spinal deformity in the form of excessive lordosis, or limited lumbosacral mobility. We prefer to observe the patient as they take 5 to 10 steps down an unobstructed path. We observe foot progression angle, stride length, and any trunk shift that occurs during the stance phase of their gait. Gait can be classified as antalgic gait, shorts striding gait, avoidance gait, Trendelenburg gait, or excessively internally or externally rotated distal extremity. Functional leg length discrepancy and malalignment will typically become more apparent with a dynamic walking assessment.

Palpation

Prior to palpation, we first ask patients to localize their pain or in essence, "self-palpate" the region of maximum symptoms. Some patients will be very focal in their description, but others may struggle to pinpoint the exact source of pain. Either way, discerning anterior groin pain from lateral or posterior pain will often assist in quickly focusing the differential. Tremendous variability exists in patient complaint and presentation but, in general, anterior hip pain is indicative of intra-articular pathology (labral tears, FAI or cartilage injury).[5,6] Patients will demonstrate a "C" sign cupping their hand and forming a "C" around the anterior hip and lateral thigh. Alternatively, posterior or lateral hip pain and tenderness may be associated with lumbar pathology or other extra-articular conditions. Palpation about the hip will localize and confirm which anatomic structures surrounding the hip are inflamed, irritated, or potentially injured. We prefer to perform the palpation exam with the patient supine, then lateral, and finally prone. Key structures that should be evaluated progressing from the midline to posterior include distal rectus abdominus, pubic symphysis, inguinal canal, adductor tubercle, adductor muscle belly, anterior inferior iliac spine, and hip flexor sheath/rectus femoris. With the patient in the lateral decubitus position, the tip of the greater trochanter is palpated and the gluteus medius is palpated along its course posteriorly. This is a common site of muscle weakness, contracture, and hence, tenderness. In the prone position, the ischial tuberosity, proximal hamstring origin, and muscle belly are palpated as well as the sacroiliac joint and low lumbar paraspinals.

Motion

Variations in hip ROM are typically seen with intra-articular hip pathology. In the seated position and the hips flexed to 90°, the patient's external and internal ROM can be easily

assessed as the pelvis remains in a fixed position. The supine position allows for testing of hip flexion as well as adduction and abduction and verification of internal and external rotation in varying positions of hip flexion. The lateral or prone position is preferred to assess hip extension and low lumbar motion. Decreased ROM can be a sign of soft tissue contracture, bony impingement, or degenerative hip disease. The degree of pain at the extremes of motion, if any, should be noted as well as noting compensatory movement patterns (increased lumbosacral motion). Excessive or increased ROM compared to the contralateral hip or normal anticipated range may indicate generalized ligamentous or capsular laxity or insufficiency. While performing dynamic ROM testing, one should also take note of any specific impediments to motion or mechanical symptoms such as snapping, popping, or locking. As in most orthopaedic cases, the side-to-side difference in ROM is often most telling.

Supine Examination

The supine examination begins with an assessment of limb length. A simple log roll exam is first performed to rule out more severe hip inflammation or arthritis. Palpation of the lower abdomen and core is best performed in this position. Passive hip flexion is next assessed and compared from side to side with an attention to possible recruitment of spinal motion. The Thomas test (Fig. 1) is performed by having the patient fully flex the contralateral hip to the chest. With the lumbar spine curvature zeroed, the involved hip and thigh should contact the exam table. If the thigh does not, a hip flexion contracture is present. The FABER test (flexion, abduction, and external rotation) is assessed next passively. Patients with intra-articular hip pathology and adductor contracture will show limited ROM in this position and often pain. We prefer to have the patient forcefully adduct the leg against resistance from this position as a secondary maneuver. This maneuver consistently elicits pain in setting of adductor tendonitis. A supine straight leg test is next performed. Radicular pain is indicative of lumbar pathology but is a rare finding. The Stinchfield test or resisted straight leg

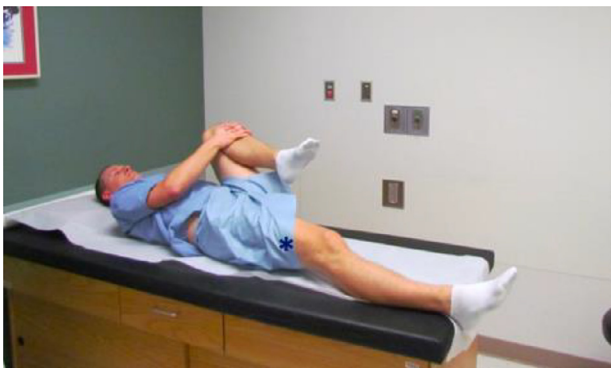

Figure 1 Thomas test/hip flexion contracture test: the contralateral leg is held in full flexion to reduce lumbar spine curvature. If the thigh of the involved leg (*) fails to reach the table, a hip flexion contracture is present.

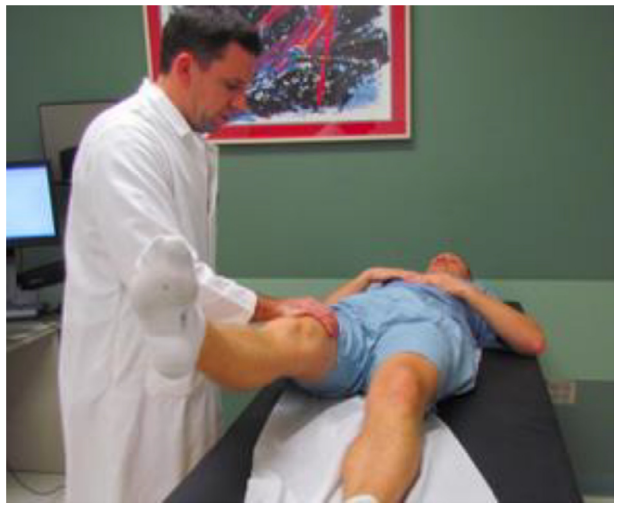

Figure 2 The Stinchfield test: the examiner places as a downward force on the proximal thigh as the patient forcefully flexes the hip with an extended knee. In a positive test, pain is elicited as the psoas compresses along the anterior acetabular labrum.

test (Fig. 2) is performed with the examiner placing downward pressure as the patient flexes the hip with a straight knee at 20°-30°. In this position, the psoas will compress the anterior labrum with resultant pain in setting of FAI and/or labral pathology. The FADDIR (flexion, adduction, internal rotation) test is performed last as it is the most sensitive and typically least comfortable for the patient. The hip is flexed to 90° and the hip adducted and internally rotated. Total motion and recruitment of lumbar motion are again assessed. This position will elicit discomfort in most patients, so we recommend asking if this recreates the patient's symptoms rather than simply asking if pain is present (Fig. 3).[7]

Lateral Examination

The lateral examination is performed with the patient lying on the uninvolved side. Palpation of the sacroiliac joint, gluteus

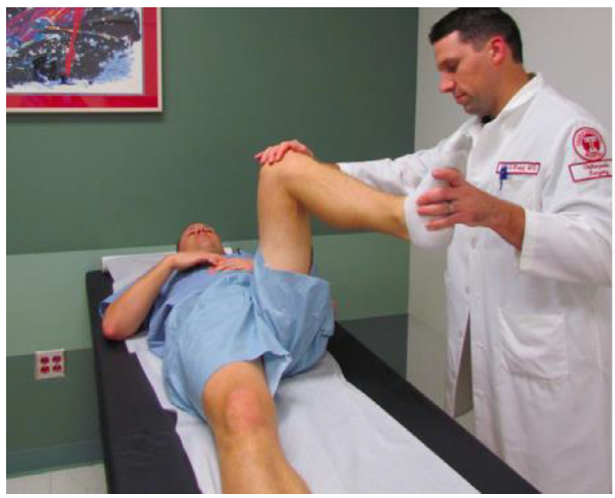

Figure 3 FADDIR (flexion, adduction, internal rotation) test will be highly sensitive for intra-articular pathology and FAI.

medius muscle belly, and greater trochanter is best performed in this position. Abductor strength testing is performed against resistance. In the piriformis active test, the patient drives the heel into the table and forcefully externally rotates the hip as the examiner provides resistance and palpates the piriformis. Pain, weakness, and potentially radicular sciatic nerve symptoms are present in patients with piriformis syndrome or pathology. Ober's test is classically described to assess tensor fascia lata contracture. In a positive test, the extended hip will not adduct down to the table passively indicating contracture. Passive adduction tests are also performed with the hip in a neutral position and flexed to assess for gluteus medius and maximus contracture, respectively. The FADDIR test is again performed to confirm findings of the supine examination. Lateral rim impingement is assessed with passive abduction and extension of the hip. Again, with all provocative maneuvers, the patient is asked if the maneuver recreates their symptoms.

Special Provocative Maneuvers

The McCarthy test is used to assess for anterior FAI or labral pathology. With the patient in a supine position, both hips are flexed and the affected limb is abducted, extended, and externally rotated. The hip is then brought back into flexion, adduction, and internal rotation. The maneuver is positive if pain is elicited or a reproducible click is present (positive McCarthy sign).[6]

The apprehension test is performed in the supine position by extending the involved hip off the side of the exam table and externally rotating the hip. Apprehension or a sense of pain may be elicited in hyperlaxity states or in the setting of postoperative capsular or labral deficiency.

Finally, we prefer to have the patient perform a resisted sit up in both the straight line and rotated positions. Pain with tenderness along the inguinal canal or pubis and pain with resisted sit up may be indicative of core muscle injury.

Imaging

Standardized radiographs should be performed on all first complaints of hip pain. We obtain the following views on all patients: supine AP pelvis, a false profile lateral view,[8] and a 45° Dunn view of the involved hip.[9] In settings of suspected arthritis or in patients of more advanced age, a standing AP pelvic view is also obtained. Cross table lateral or frog leg lateral views can be obtained if necessary. The AP film must be controlled for rotation and pelvis inclination. In an appropriate film, the tip of the coccyx will be 1.5-3.0 cm from the superior border of the pubic symphysis. The AP pelvic radiograph is used to assess the following parameters: neck shaft angle, lateral center edge angle, acetabular inclination, head sphericity and anterior/posterior wall orientation (crossover).

Radiographic Parameters

The neck shaft angle (Fig. 4) is formed as the angle between the long axis of the proximal femoral shaft and the femoral neck.

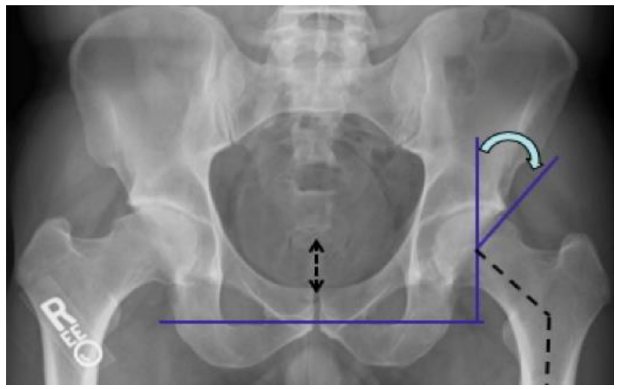

Figure 4 AP pelvis radiograph: on the appropriately positioned film, the tip of the coccyx will be 1.5-3.0 cm from the superior border of the pubis (dashed arrow). The neck shaft angle is first assessed as the tangent of the lines drawn along the long axis of the femur and the long axis of the femoral neck (dashed line). The lateral center edge angle (LCEA) is created from line drawn perpendicular to the horizontal axis through the center of the head and a second line from the center of the femoral head to the lateral extent of the sclerotic acetabular roof (blue line). (Color version of figure is available online.)

Normal range is between 125° and 140°. Angles greater than 140° represent coxa valgus and less than 125° coxa varus. The lateral center edge angle is used to assess the degree of acetabular coverage. The lateral center edge angle (Fig. 4, blue line) is formed by a line through the center of the femoral head perpendicular to the horizontal pelvic axis, correcting for tilt, and a line from the center of the head to the lateral edge of the acetabulum.[10] Normal lateral center edge angles (LCEAs) range from 25° to 42°. LCEA less than 25° represents insufficient coverage or dysplasia states. LCEAs >40° are seen in states of over-coverage either focal or global. The acetabular inclination angle or Tonnis angle is formed by a horizontal line and a line drawn from the lateral edge of the acetabulum to the lowest point of the sclerotic zone of the acetabular roof. Normal Tonnis angles range from 0° to 10°. An elevated Tonnis angle >10° is often seen with instability or hip dysplasia. A negative Tonnis angle <0° is representative of over-coverage or pincer type FAI. Head sphericity should be assessed on AP and lateral projections. On the AP view, a reference "perfect circle" is created. The head is classified as aspherical if the epiphysis extends >2 mm beyond this perfect circle.[11] Acetabular version describes the position of the acetabulum and is measured radiographically by the presence or absence of a "crossover sign." In the anteverted acetabulum if the anterior wall of the acetabulum does not cross the line of the posterior wall of the acetabulum before reaching the lateral extent of the sourcil. If the acetabulum is retroverted, the line along the anterior wall will cross the line along the posterior aspect of the rim before reaching the sourcil ("positive crossover sign") (Fig. 5) Importantly, acetabular retroversion typically refers to a state with a deficient posterior wall. A positive crossover sign can be seen with focal or cranial retroversion and no posterior wall deficiency. Close attention to radiographs and additional use of CT scan may be necessary to fully assess acetabular version. Recent studies have shown that supine films may overestimate acetabular retroversion and abnormalities of the anteroinferior iliac spine (AIIS) may create a "false crossover

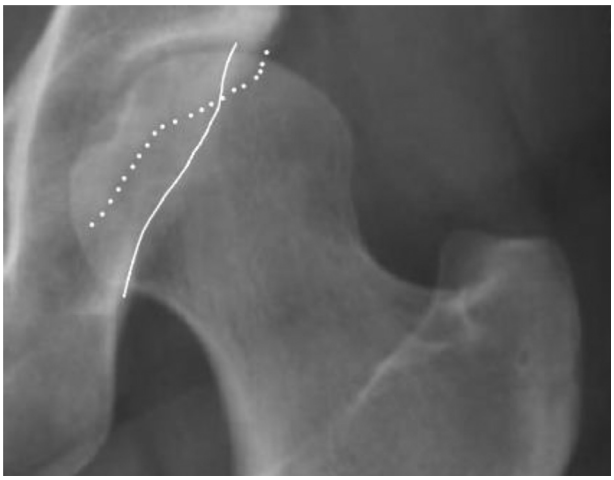

Figure 5 The "crossover sign" is formed as the anterior wall (dotted line) crosses lateral to the posterior wall (solid line) indicating acetabular retroversion. Note that this measure is only valid on an appropriately centered AP pelvis view.

sign."[12] If question remains, we obtain CT scan to better define osseous anatomy.

The Dunn lateral will best visualize the head-neck junction anatomy. The 90° *Dunn* radiograph is shot with the patient supine on the x-ray table and the hip flexed 90° and abducted 20° while neutral rotation is maintained. The beam is directed at a point midway between the AIIS and the pubic symphysis.[13] Head sphericity is again assessed with reference circle technique. Head-neck offset is assessed grossly by comparing the radius of curvature of the posterior and anterior femoral head-neck junction. If the concavity is symmetric from anterior to posterior, heck-neck offset is "normal." If the anterior neck is convex as opposed to concave a CAM deformity is present. The anterior femoral head neck offset can be measured as described by Eijer et al.[14] A line is drawn bisecting the longitudinal axis of the femoral neck (A) and a parallel line along the narrowest portion of the femoral neck

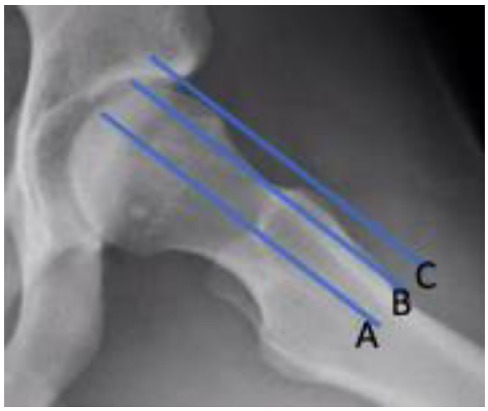

Figure 6 Head-neck offset depicted in postoperative left hip: parallel lines are created relative to the long axis of the femoral neck. The distance between the greatest depth of the concavity of the femoral neck (B) and the offset of the femoral head (C) represent the measure of head-neck offset.

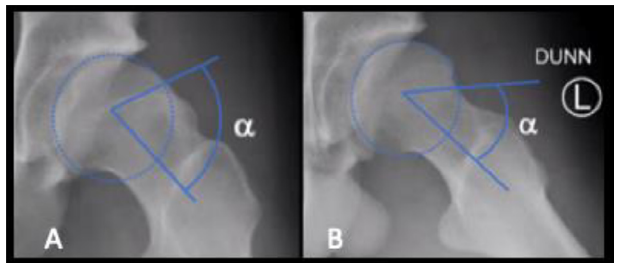

Figure 7 The alpha angle is created from a line drawn along the long axis of the femoral neck to the center of the femoral head and a line to the point where the head-neck junction first deviates from the reference circle. (A) Left hip preoperative elevated alpha angle; (B) reduction in alpha angle is seen after cam resection.

(B). A third parallel line is drawn along the anterior border of the femoral head (C). The perpendicular distance between lines B and C represents the femoral head-neck offset (Fig. 6). The alpha angle is measured by first drawing a reference circle along the posterior concavity of the femoral head-neck junction. An angle is created from a line drawn along the long axis of the femoral neck to the center of the femoral head and a line where the head neck junction first deviates from the reference circle (Fig. 7). Angles greater than 42°-45° suggest CAM morphology FAI.

Computed Tomography

Computed tomography (CT) can be obtained in appropriate clinical settings to better define the osseous anatomy of the proximal femur and acetabulum. Multiplanar imaging and 3-dimensional (3D) reconstruction models can assist in characterization of atypical cam deformity, AIIS morphology or extent of acetabular dysplasia. The use of CT scan in FAI can allow for more accurate and complete measurement of key radiographic parameters.[15-17] For example, the alpha angle can be measured in multiple planes and at multiple positions along the head-neck junction. Used in conjunction with 3D reconstruction, the surgeon can confidently predict the size, shape, and precise location of cam and pincer deformity and the extent of impingement. Commercially available software programs allow for assessment pre- and postoperatively. Abnormalities of acetabular or femoral version may predispose patients to limited ROM, FAI, and intra-articular damage. In a recent study, Kraeutler et al demonstrated that femoral version abnormalities significantly outweigh the effect of cam-type impingement on passive hip internal rotation ROM. They also noted that cam deformity more directly impacts hip flexion irrespective of femoral version.[18] These findings are important considerations for preoperative planning, goal setting, and patient counseling.

MRI/MRA

Classically, MRI of the hip has been used to evaluate hip pathology such as avascular necrosis, loose bodies, labral

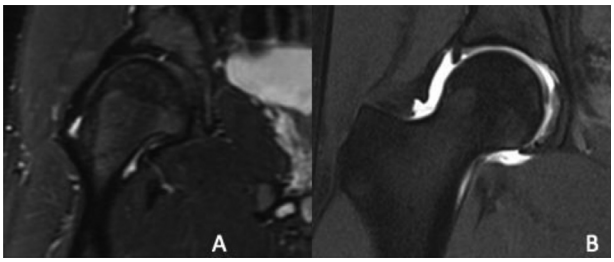

Figure 8 Noncontrast MRI (A) vs. MR arthrogram of the right hip. MRA has been shown superior sensitivity and specificity in detection of labral and cartilage pathology.

pathology, and/or periarticular muscle-tendon injury. Recently, MRA and special sequence MRI have been employed to better define the early stages of hip degenerative disease. MRI and MRA can better define subtle states of impingement and dysplasia and also provide the best assessment of cartilage and labrum. The use of MRI vs MR arthrogram is institution specific. MRI and MRA are both highly sensitive in detecting extra-articular pathology of the hip but MRA has shown superiority in detection of intra-articular pathology, specifically labral tears (Fig. 8). In detection of labral tears, meta-analysis data demonstrate sensitivity and specificity of 66% and 79% for conventional MRI compared to 87% and 64% for MR arthrography.[19-21] MRA is also superior for evaluation of articular cartilage, with sensitivities ranges of 71%-92% compared to 58%-83% for conventional MRI.[22-24]

We prefer to obtain MRA for routine preoperative planning. MRA is a minimally invasive and consistent manner by which to best evaluate the extent of cartilage and labrum injury. An understanding of the degree of cartilage degeneration will guide the decision to proceed or not to proceed with surgical intervention while also providing information that can potentially predict the long-term prognosis for the patient's hip.

At our institution, all patients are examined with the use of a 1.5T or 3.0T high-field scanner. A surface coil can be used to improve spatial resolution. Often patients will present with nonarthrogram series or low-resolution open MRI studies having been previously performed. The hip is a deep joint with thin cartilage. Therefore, low-resolution studies will typically underestimate the extent of hip degeneration and may result to poorly informed surgical planning. If necessary, we will obtain new studies before proceeding with surgical intervention. The arthrogram portion of the study can be performed under C-arm or ultrasound guidance.

MRI protocols for imaging the pelvis and hip vary across institutions, but we and most authors recommend inclusion of several key elements. First, large field-of-view images of the pelvis should be obtained spanning from the proximal iliac crests down to the level of the lesser trochanters. Including this in your standard protocol will ensure that other pelvic pathology, mimicking hip pain, is not overlooked. Coronal T1-weighted images will show anatomy (muscle, tendon, and bone) in greater detail, while T2-weighted with fat suppression or short tau inversion recovery sequences are obtained in the coronal and axial planes to evaluate for fluid collection or muscle/tendon edema or injury. Focused imaging of the involved hip is next performed with a surface coil. Small field of view imaging with T2-weighted fat suppression will provide the best visualization of the labrum and cartilage. Minimizing slice thickness (2-3 mm) without interslice gaps is best to evaluate the labrum. Cartilage evaluation can be challenging as plane selection may be difficulty along the highly curved acetabulum and femoral head. Cartilage is relatively thin and the 2 surfaces are closely opposed making hip cartilage highly susceptible to partial volume averaging[25] Conventional axial, sagittal, and coronal plane views are obtained but we highly recommend inclusion of either an oblique axial or radial imaging. Radial imaging will provide superior cross-sectional assessment of cartilage and labrum.[26]

MRI Interpretation

A systematic approach to MRI interpretation is recommended. A working diagnosis of impingement, instability, or other condition should precede the decision to obtain advanced imaging. MRI should confirm findings but also lends valuable information about the status of cartilage and labrum which should be discussed in preoperative conversations with the patient. It is essential for the treating physician to develop comfort with MRI interpretation. Close collaboration and frequent conversation with a musculoskeletal radiologist are key to fully appreciate the extent of hip disease noted on MRA.

We begin first with an assessment of osseous anatomy to confirm or refute our findings suggested on plain radiographs. Acetabular version can be measured at various locations. In settings of global or focal over-coverage, the acetabular rim is closely inspected for signs of calcification or reactive bone formation. The femoral head-neck junction is inspected on coronal, sagittal, and axial views. We first evaluate overall contour for the presence or absence of normal concavity. Alpha angle measures can be recreated to confirm radiographic findings. Impingement cysts are closely linked to the region of maximal impingement and are therefore, typically present along the anterior neck. The femoral neck may show minimal thickening or reaction as seen in pincer morphology or the presence of a large cam lesion. Most clinical scenarios involve combined impingement and again, MRI findings should confirm the findings suspected based on plain radiographs.

Ultrasound

In office, ultrasound utilization for diagnostic and interventional purposes continues to rise in orthopaedics and sports medicine. In experienced hands, diagnostic can provide valuable real-time assessment of muscle injury, tendinopathies, bursal pathologies, effusion, and cortical surface lesions. Dynamic evaluation of snapping hip conditions can easily be performed. Authors have suggested that ultrasound is of equivalent sensitivity and specificity for the detection of acetabular labral tears.[27] However, in our practice, we still continue to obtain MRA as a best assessment of articular cartilage or hip degeneration. If necessary, diagnostic injections are

performed in office with ultrasound guidance. This allows for immediate assessment of response to treatment.

Conclusion

Accurate diagnosis is the first step to effective and appropriate management of hip pathology in athletes. Athletic hip injuries are becoming increasingly common across all sports and competitive levels. Sports medicine physicians will frequently encounter hip injury. Focused but comprehensive physical examination can help to narrow the potentially overwhelmingly broad differential diagnosis. Close interpretation of advanced imaging should confirm the diagnosis and assist the surgeon in predicting short- and long-term prognosis following intervention.

Declaration of Competing Interest

The authors declare no conflicts of interest and do not have any financial disclosures.

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