Original Article

Preoperative Dynamic Hip Examination Under Fluoroscopic Guidance Enhances the Understanding of Femoroacetabular Impingement Pathology and Treatment Planning

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Purpose: To review the relative accuracy of preoperative magnetic resonance imaging (MRI) and fluoroscopically guided examination-under-sedation (EUS) findings and to explore the validity of the anterior acetabular sector angle (AASA) as a radiologic MRI-based marker of anterior acetabular coverage in pincer-type impingement. **Methods:** A cohort of 150 consecutive patients undergoing primary hip arthroscopy for femoroacetabular impingement (FAI) in 2018 to 2019 was reviewed. The inclusion criteria were pure FAI unilateral symptomatic pathology and the availability of complete data sets (MRI, EUS, and intraoperative records). Preoperative MRI and EUS findings were compared with gold-standard intraoperative arthroscopic findings, specifically evaluating the alpha angle in the presence of cam lesions, AASA in the presence of pincer lesions, as well as soft-tissue lesions. An alpha angle greater than 50° and an AASA greater than 65° were deemed pathologic. **Results:** The patient cohort included 78 women and 72 men with an average age of 38 years (range, 18-53 years). Intraoperatively, pincer lesions were present in 20% of patients; cam lesions, 26%; and mixed impingement, 54%. MRI versus EUS correctly identified pincer lesions in 36% versus 89% of cases and identified cam lesions in 44% versus 77% of cases. MRI findings characterizing labral tears and articular cartilage pathology were accurate in 80% and 10% of cases, respectively. Although there was no difference in the AASA between pure pincer- and mixed-type impingements (62° and 63°, respectively; $P = .62$), there was a statistically significant difference in reported AASA values between pure cam-type impingement and impingement involving the presence of pincer lesions (57° and 63°, respectively; $P = .03$). Furthermore, 31% of patients with intraoperatively identified pincer lesions had an AASA of 60° to 65°. **Conclusions:** Fluoroscopic EUS is accurate in characterizing FAI pathology. In addition, MRI is useful to diagnose or rule out non-FAI pathology, ascertain labral pathology, and outline hip alignment. These methods of preoperative planning are complementary. **Level of Evidence:** Level IV, therapeutic case series.

In suitable accordance with the modern trends of minimally invasive approaches and evidence-based medicine, hip arthroscopy has expanded over the past 2 to 3 decades in terms of the number of procedures, the scope of treatable pathology, and the level of the relevant evidence base.[1,2] Critically, our understanding of the underlying pathology and its management strategies has significantly evolved. Labral tears and chondral damage in physiologically young patients are uncommon in the absence of underlying intra- or extra-articular morphologic abnormalities.[3,4] This concept is fundamental because, without primarily addressing the underlying pathoanatomy, the outcomes of surgical interventions are liable to be dominated by failure and recurrence.

It is becoming increasingly clear that meticulous patient selection, informed management decisions,

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and comprehensive operative expertise are predictably rewarded with credible levels of native hip survival, excellent mid- to long-term clinical outcomes, and low complication rates after hip arthroscopy.[5-7] Detailed understanding of the intra-articular pathoanatomy leads to more targeted and purposeful interventions by a treating surgeon. Most hip arthroscopies are performed for labral tears as sequelae of femoroacetabular impingement (FAI)—a dynamic phenomenon with a complex interplay of kinematics and anatomy.[2,4,8] Although conversion of 2-dimensional images into 3-dimensional paradigms is routine in clinical orthopaedic practice, the static nature of magnetic resonance imaging (MRI) scanning is a significant limitation. As a result, this conversion process is not consistently reliable, as evidenced by persistent impingement or overcorrection being the most common reason (79%-97% of cases) for revision hip arthroscopy.[4,9-13] The understanding of the precise pathology preoperatively is perhaps more essential for hip arthroscopy because joint access and visualization are more challenging and limited, thus demanding a more focused approach if significant capsular injury is to be avoided.

Inadequately addressed FAI is in part ensuing from the difficulty of achieving a comprehensive understanding of the hip pathoanatomy and kinematics. Radiologic criteria defining pincer-type impingement are relatively lacking.[14] Although frequently used, the lateral center-edge angle (LCEA) is likely to be more useful in quantifying superior acetabular under- or over-coverage, that is, dysplasia or profunda morphology.[15] FAI is a phenomenon involving the anterosuperior acetabulum, and thus, standardizing the quantification of anterior acetabular coverage in the axial plane is essential.[16]

Fluoroscopically guided examination under anesthesia—or under sedation as performed in our institution (examination under sedation [EUS])—is a dynamic test seeking to reproduce impingement and determine the contributing osseous pathomorphology. EUS can facilitate preoperative planning of the resection, whereas intraoperatively, it can serve as a real-time surgical decision tool.[5] However, the evidence on the value of preoperative EUS as a planning tool for arthroscopic intervention is scant.

The purposes of this study were to review the relative accuracy of preoperative MRI and fluoroscopically guided EUS findings and to explore the validity of the anterior acetabular sector angle (AASA) as a radiologic MRI-based marker of anterior acetabular coverage in pincer-type impingement. In the context of hip arthroscopy for FAI, we hypothesized that MRI findings alone would provide insufficient information to enable thorough preoperative planning. We also hypothesized that the AASA would be valid as a radiologic MRI-based marker of anterior acetabular coverage in pincer-type impingement.

Methods

Patient Selection

A cohort of 150 consecutive patients (an approximate 1-year workload) undergoing primary hip arthroscopy for FAI between January 2018 and February 2019 was retrospectively reviewed. The start date was randomly selected as the beginning of a year, and the time frame was determined by the arthroscopy date of the last consecutive patient (patient 150) fulfilling the eligibility criteria. The inclusion criteria included pure FAI unilateral symptomatic pathology and the availability of complete data sets (MRI, EUS, and intraoperative records). Bilateral hip arthroscopies were excluded. Abnormal acetabular and femoral version, although potentially causing impingement, primarily required reorientation osteotomy plus or minus hip arthroscopy, and these patients were excluded.

Imaging Evaluation

All patients underwent diagnostic plain radiography and MRI scans. All MRI scans were non-contrast 3-T scans, were reported by experienced musculoskeletal radiologists, and were individually reviewed during data collection by the lead author (V.G.), who was not blinded.

The radiologic description of underlying FAI pathology relevant to this study was based on preoperative MRI reports. The possible presence of cam lesions was always linked with elevated alpha angles, whereas the potential presence of pincer lesions was more vague and based on the general appearance (including acetabular over-coverage) supported by the sector angles. Therefore, the alpha angle and AASA (Fig 1) were specifically selected to indicate cam and pincer lesions as single measures, respectively.

The alpha angle was measured on oblique axial magnetic resonance images of the femoral neck at the point of maximal prominence. The AASA was measured on axial magnetic resonance images through the center of the femoral head (Fig 1B). An alpha angle greater than 50° was deemed pathologic and suggestive of a cam lesion.[17] An AASA of 50° to 65° was considered normal.[18,19] Therefore, an AASA greater than 65° was deemed pathologic and suggestive of a pincer lesion in our analysis.

Examination Under Sedation

All patients underwent an EUS either at the time of injection or immediately preoperatively. Although we aimed to offer EUS and hip injection on a separate occasion from hip arthroscopy to allow patient

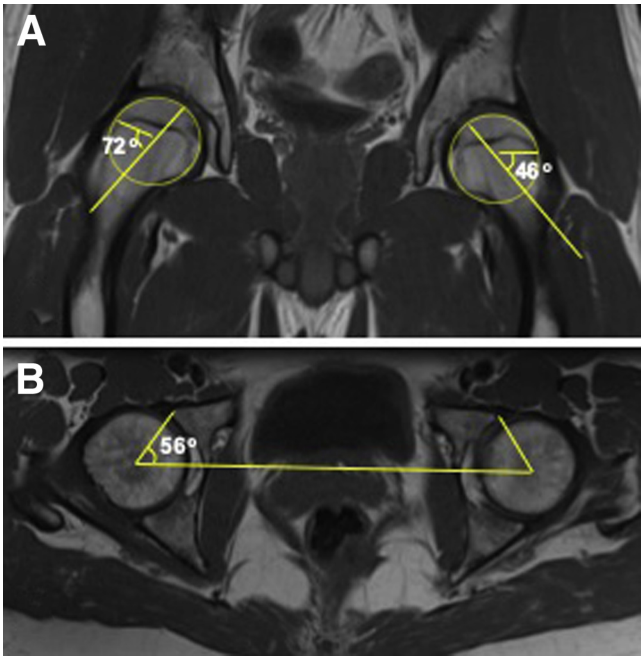

Fig 1. (A) Coronal magnetic resonance image of bilateral hips. The alpha angle (α) was measured as the angle between the line drawn through the centers of the femoral neck and head and the line drawn from the center of the femoral head to the anterior point, where the distance exceeds the radius of the femoral head. The pathologic alpha angle on the right should be noted. (B) An axial magnetic resonance image through the center of the femoral head is used for measurement of the anterior acetabular sector angle, that is, the angle between the inter-capital centerline and the line from the center point of the head to the anterior acetabular rim.

pre-habilitation, the practical reality dictated that 49 EUS procedures (33%) were performed immediately before arthroscopy, in which case the steroid injection was not performed. All EUS procedures were performed by the senior author (A.J.L.), who was not blinded, reflecting the standard clinical practice.

EUS focused on delineation of cam and pincer lesions,[20] as well as the point of contact (osseous impingement) between the femoral neck and acetabulum. This was achieved by internally rotating and flexing the hip and, to enable fluoroscopic imaging, providing additional abduction until the head began to lift out of the acetabulum. Osseous impingement at the head-neck junction indicated a cam lesion and/or reduced of head-neck offset, whereas contact with the more distal neck indicated pincer-type impingement and/or over-coverage (Fig 2). By moving the hip from extension into deep flexion (with corresponding flexion of the pelvis), acetabular visualization was thought to be achievable at approximately the 11- to 3-o'clock position. Other findings of EUS were not relevant to this study. An injection of steroid (80 mg of Depo-Medrone with local anesthetic; Pfizer) was delivered as both a diagnostic intervention and therapeutic intervention at the time of EUS if performed on a separate occasion from hip arthroscopy.

Arthroscopy: Surgical Technique

Hip arthroscopy was performed by the senior author with the patient supine, ensuring that a focused effort was made to identify pincer and cam lesions. The former was achieved by exploration of the capsulolabral recess, whereas the latter was achieved by a thorough visual inspection of the femoral neck from the 10- to 4-o'clock position, with limited capsulotomy performed in rare cases when required. Diagnostic arthroscopic findings of interest included the state of the articular cartilage; the extent and location of labral damage; and specific to identification of the exact FAI morphology, the location and size of cam and pincer lesions. A pincer lesion was defined as the presence of bony outgrowth beyond the level of the chondrolabral junction in the capsulolabral recess. Therapeutically, all cases underwent endoscopic decompression, synovectomy, acetabular rim trimming, labral stabilization, acetabular chondroplasty, and/or femoral osteochondroplasty. Full EUS under fluoroscopic guidance was performed immediately prior to arthroscopy in all cases, whereas intraoperatively, it was limited by the leg traction setup. Postoperative EUS was again performed to ascertain the change in range of motion afforded by bony resection.

Data Analysis

For the purposes of comparison between MRI, EUS, and arthroscopic findings, recognized cam- and pincer-type lesions were analyzed separately as 2 distinct groups; in cases of mixed-type impingement, cam and pincer lesions were each added to their respective groups. Subsequently, the findings of MRI and EUS were compared with those of arthroscopy, with the latter designated the gold-standard benchmark. A similar process was undertaken for labral and chondral lesions.

Data analysis was performed using Microsoft Excel for Mac (version 16.16.21; Microsoft) and presented as comparisons of the 3 analyzed interventions. Univariate analysis was performed using the parametric paired Student *t* test. Graphs were generated using Prism 8 for MacOS (version 8.4.3; GraphPad Software).

Results

Patient Demographic Characteristics and Distribution of FAI Pathoanatomy

Of 150 patients, 78 were women and 72 were men; the average age was 38 years (range, 18-53 years). During arthroscopy, isolated pincer lesions were identified in 20% of patients; cam lesions, 26%; and mixed impingement, 54%. The prevalence of the impingement type between the 2 sexes was as follows: Pincer

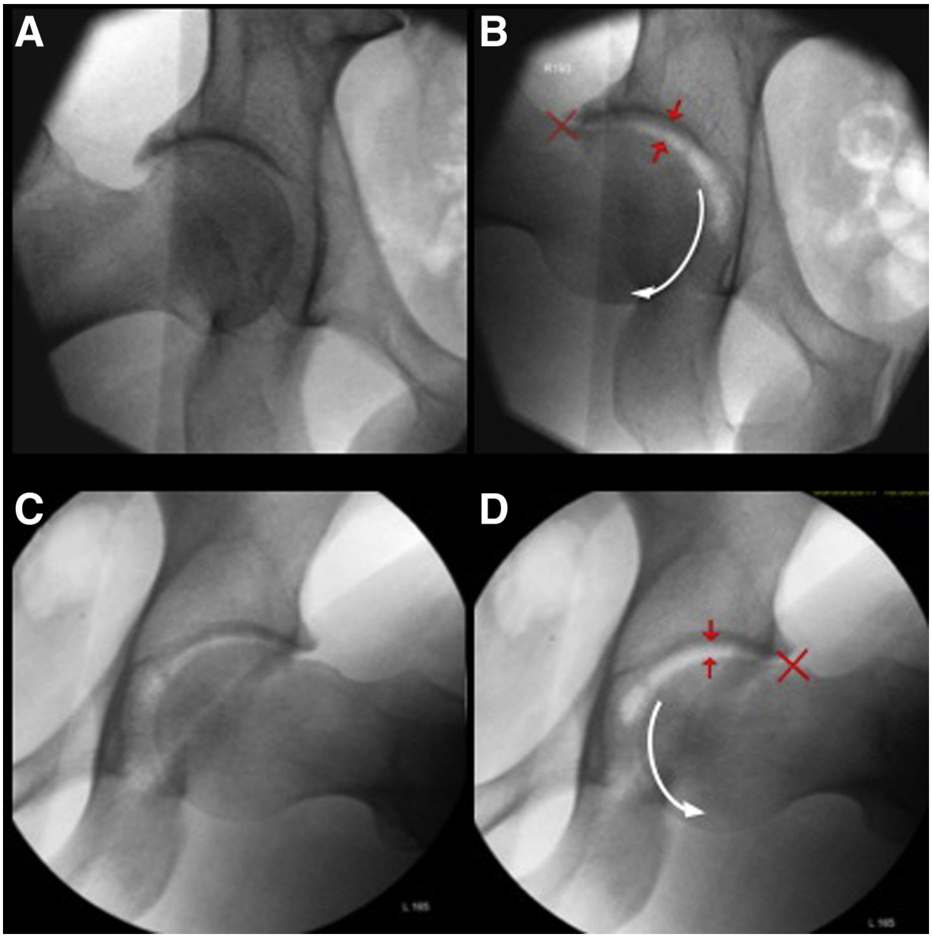

Fig 2. Fluoroscopic images of right hip undergoing examination under anesthesia with flexion and 20° of external rotation (A) and with flexion, 10° of internal rotation, and 20° of abduction (B). The prominent pincer lesion should be noted. The point of collision and impingement between the acetabular rim and the femoral neck (red cross) should be noted. With further abduction (white arrow to indicate head rotation within acetabulum), the femoral head lifts out of the acetabulum (the joint space superiorly [indicated by red arrows] widens). Fluoroscopic images of left hip with flexion and 20° of external rotation (C) and with flexion, 10° of internal rotation, and 20° of abduction (D). The prominent anterosuperior cam lesion should be noted. It should be noted that the rim-neck collision occurs more proximally on the femoral neck.

type was present in 90% of women and 10% of men; cam type was present in 30% and 70%, respectively; and mixed-type FAI was present in 65% and 35%, respectively (Fig 3).

Data Analysis

When compared with the arthroscopic benchmark, MRI findings correctly identified cam lesions (alpha angle $> 50°$) in 44% of patients and pincer-type lesions (AASA $> 65°$) in 36% of patients (Fig 4A). Although there was no difference in the AASA between pure pincer- and mixed-type impingements (62° and 63°, respectively; $P = .62$), there was a statistically significant difference in reported AASA values between pure cam impingement and impingement involving the presence of pincer lesions (57° and 63°, respectively; $P = .03$). Furthermore, 31% of patients with intraoperatively identified pincer lesions had an AASA of 60° to 65°. In contrast, EUS correctly predicted the presence of cam lesions and pincer-type impingement in 89% and 77% of cases, respectively (Fig 4B). Compared with intraoperative findings, the location and extent of MRI-reported labral tears and articular cartilage pathology were accurate in 80% and 10% of cases, respectively (Fig 4C).

Discussion

In this study, the effectiveness of EUS in predicting impingement patterns was shown to be superior to that of MRI scanning. Our findings support the use of preoperative EUS under fluoroscopic guidance owing to its value in informing subsequent definitive re-sculpting. In turn, the ensuing enhanced ability to accurately and reproducibly identify impingement lesions should contribute to improved postoperative outcomes and a reduced rate of revision.[4,9-11] We suggest that the advantage of EUS is its dynamic nature, allowing visualization of bony anatomy from a range of angles and more accurate identification of the impingement location.

In contrast, MRI scanning is a static investigation. The resultant measurements are dependent on cross-sectional acquisition and are often open to interpretation errors even in the expert hands of musculoskeletal radiologists. MRI, therefore, is a valuable adjunct in defining the pathoanatomy while being innately

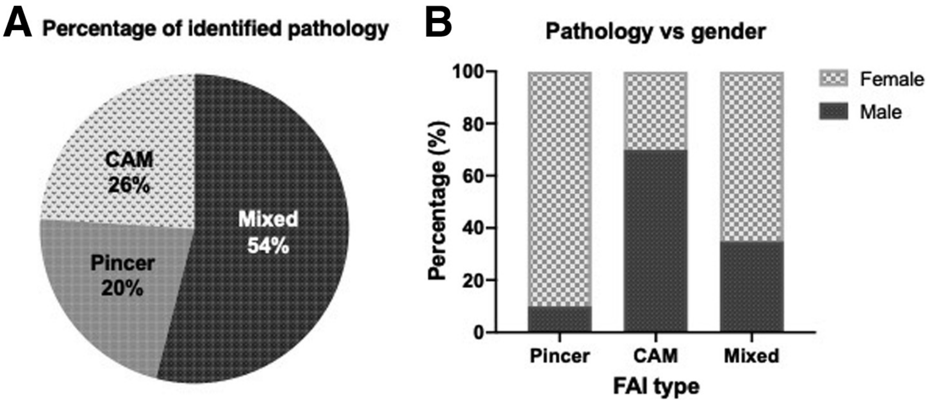

Fig 3. (A) Prevalence of 3 individual types of femoroacetabular impingement within patient cohort. (B) Prevalence of each femoroacetabular impingement (FAI) type between sexes.

inaccurate in defining dynamic phenomena (i.e., FAI). We value MRI findings as a guide that is useful to diagnose or rule out non-FAI pathology, ascertain labral pathology, and generally outline the skeletal alignment. We believe that the sensitivity of a standard MRI study in defining the causative osseous FAI lesions is relatively low, although the specificity, once the lesions are identified, is likely adequate. Definition of the exact location and extent of FAI lesions can be enhanced with application of radial sequences around the axis of the femoral neck, enabling improved assessment of the 3-dimensional morphology of the acetabulum and femoral head-neck junction.[21]

A debate on the relative benefits of magnetic resonance arthrography (MRA) versus standard MRI for the detection of labral and chondral lesions is ongoing.[22,23] A recent study showed high sensitivity and accuracy of a non-arthrographic 3-T MRI technique in evaluating labral and chondral lesions.[24] In our study of conventional 3-T MRI, the sensitivity and specificity for labral pathology detection were 80% and 100%, respectively, whereas those for articular cartilage detection were 11% and 42%, respectively, showing the difficulty of reliable chondral lesion detection. A number of techniques have been suggested to improve the diagnosis of chondral lesions and degeneration, including traction MRA, biochemical MRI and/or MRA, delayed gadolinium-enhanced magnetic resonance imaging of cartilage (dGEMRIC), T2/T2* mapping, and T1-rho mapping.[21]

Although MRI became the mainstay of the preoperative investigation protocol for FAI, computed tomography (CT) scan, owing to its superior contrast properties, remains a benchmark for bone morphology assessment. However, Malloy et al.[25] suggested that MRI was valid for accurate assessment of the proximal

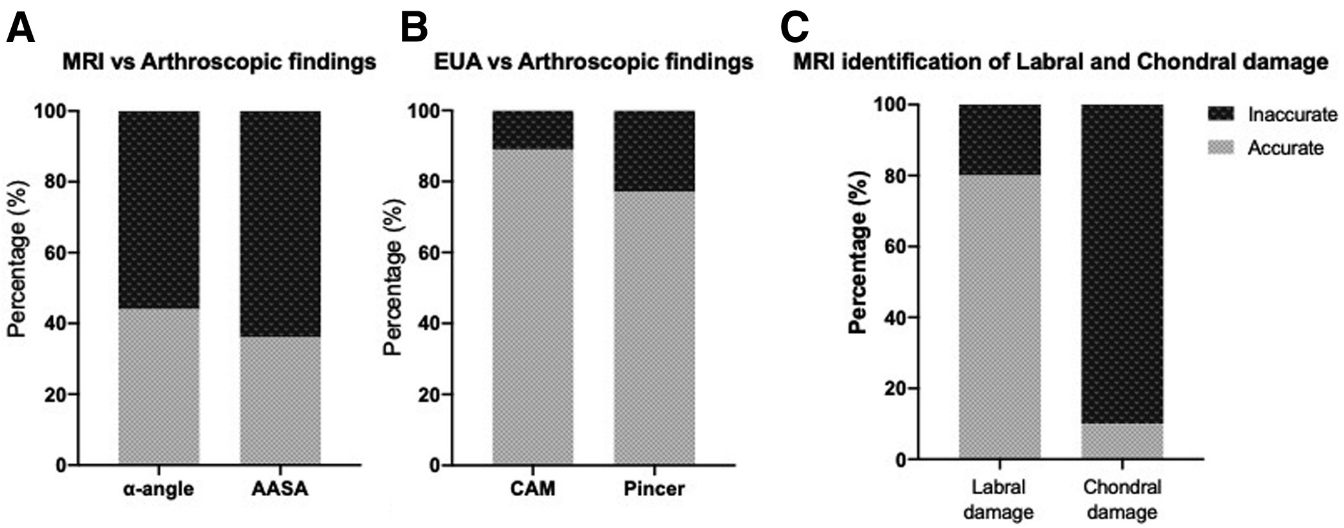

Fig 4. (A) Comparison of magnetic resonance imaging (MRI)—reported findings of osseous morphology versus benchmark arthroscopic findings. (B) Comparison of examination-under-sedation findings versus benchmark arthroscopic findings. (C) Comparison of magnetic resonance imaging—reported findings of labral and articular cartilage (chondral) lesions versus benchmark arthroscopic findings. (AASA, anterior acetabular sector angle; EUA, examination under anesthesia.)

femoral anatomy. An innovative CT application to address the dynamic nature of FAI is in dynamic assessment of FAI with CT-based 3-dimensional simulation modeling (HipMotion).[26] Another low-radiation CT-based tool introduced to enhance the accuracy of arthroscopic FAI re-sculpting is HipMap/HipCheck (Stryker).[27] HipMap/HipCheck maps intra-articular pathomorphology as a deviation from morphology found in asymptomatic patients with 95% confidence,[28] in addition to providing insight into relative acetabular version, but is not a dynamic impingement collision map.

Traditional CT scans are associated with significant patient radiation exposure (9.68 $\pm$ 6.67 mSv), and low-dose CT sequences (effective dose, 0.97 $\pm$ 0.28 mSv) are currently preferred.[29] We limit CT use to cases in which there is clinical or radiologic suspicion of malrotation or malalignment. To achieve an understanding of FAI pathomorphology and kinematics, we advocate routine inclusion of EUS under fluoroscopic guidance in preoperative planning (maximal dose, 0.2 mSv), negating the general anesthetic risk while minimizing the radiation exposure. We do, however, accept that radiation is inevitable in EUS procedures and remain aware of the evolution of other valuable complementary tools.

An interesting direction for further research is correlation of accuracy between a CT-based dynamic simulation model and EUS. Another consideration is the definition of impingement because we focused on bone-against-bone collision whereas abnormal contact between the labrum and the femoral head-neck junction could still lead to labral injury. In most cases, the labrum should be able to adjust to such contact, and the most severe labral injury is likely to occur during its entrapment between the 2 colliding bony structures (i.e., acetabular rim and femoral neck). Hence, an MRI-based collision model of impingement may be more appropriate. Additionally, an evaluation of these dynamic modeling platforms against standard high-resolution MRI scans with radial sequences would yield further insight. The clinical application of more advanced investigation techniques in the landscape of value-based medicine and clinical rationing will require sound evidence—and has to be weighed against relatively accessible and inexpensive alternatives such as EUS under radiologic guidance.

The criteria for quantification of acetabular coverage in pincer-type impingement are often plain radiography based and of poor accuracy.[14,30-33] CT-based criteria for acetabular coverage measurements in hip dysplasia, not FAI, included acetabular anteversion, the LCEA, the acetabular index, the anterior center-edge angle, the AASA, and the posterior acetabular sector angle.[19] There is a paucity of evidence on the appropriate CT- or MRI-based criteria to characterize pincer-type FAI, particularly anteriorly.[14,16] In a study with Level III evidence, an LCEA of 40° or greater as measured on MRI scans showed high sensitivity and specificity in predicting acetabular over-coverage.[34] However, in pincer-type FAI, labral and/or articular surface damage was shown to occur in the zone of hip impingement in the anterosuperior quadrant approximately at the 1:30 clock-face position to 2-o'clock position as identified on routine CT scans or determined using HipMotion.[26,35] The AASA was introduced as a CT-based marker of acetabular morphology[18] and measures acetabular coverage at around the 3-o'clock position. Therefore, we postulated that the AASA rather than the LCEA was more relevant as a single radiologic parameter to define acetabular over-coverage.

The AASA in pure cam-type impingement was found to be significantly lower than that in the presence of pincer lesions (57° vs 63°, $P < .05$), and the difference in the AASA between pure pincer- and mixed-type impingements was not significant (62° vs 63°, $P = .62$). The AASA as a marker appears to be sensitive to differentiation between the presumed normal acetabula in pure cam-type impingement and the acetabula with over-coverage due to the presence of pincer lesions. However, the AASA's overall sensitivity in identifying pincer lesions at the current threshold of 50° to 65° is low (36%). AASA measurements are known to vary with pelvic tilt.[36] Although the mean normal AASA in the anatomic position was 67°, it was shown to change by 1.07° for every 1° change in pelvic obliquity. Supine patient positioning during MRI scanning leads to a reduction in pelvic tilt and an increase in acetabular anteversion. This suggests that revision of the upper normal limit of the AASA may be warranted for the purposes of MRI-based assessment of anterior acetabular over-coverage, given that in our study, the AASA was 60° to 65° in 31% of cases. However, any acetabular coverage criteria are pelvic tilt dependent, and standardized MRI assessment is crucial.

Our MRI scanning followed a standardized protocol, although it did not routinely accurately account for pelvic tilt and the measurement landmarks were open to a degree of interpretational error. This could explain our low rate of MRI-based identification of pincer-type impingement (36%) when the deformity was defined by an AASA greater than 65°. Despite the potential advantage in using the AASA as a measure of anterior acetabular over-coverage, we believe that a combination of the AASA and the LCEA could be more reliable in capturing anterosuperior over-coverage, warranting future investigations.

Although it is valuable to define the effectiveness of radiographic criteria in defining the underlying pathoanatomy, with FAI being a dynamic phenomenon, a combination of acetabular and femoral factors is likely to be more relevant. We again suggest that static radiologic investigations are not a viable alternative for dynamic investigation or examination of joint kinematics.

Preoperative identification of pincer-type impingement is important because, intraoperatively, a deliberate effort is required for its identification, potentially explaining the low reported prevalence rate of pincer-type impingement (17% and 8% for mixed and pure pincer-type impingement, respectively, in a 348-patient series).[37] Our experience suggests a much higher prevalence of pincer lesions, revealed as 54% and 20% for mixed and pure pincer-type impingement, respectively. In our practice, if pincer lesions fail to be identified preoperatively, purposeful intraoperative steps are undertaken to ensure that pincer lesions are not missed. The higher prevalence of pincer lesions in this study and our practice could potentially be a result of a specific patient cohort we are treating in our center. However, the capture population of our center exceeds 600,000, and additionally, we take referrals from outside the region, likely making our findings reasonably generalizable.

Finally, routine preoperative hip injections, despite high sensitivity in identification of intra-articular pathology with a positive response, are used relatively infrequently (in 7% of patients investigated for FAI).[38] We routinely use hip injection as both a diagnostic measure and a therapeutic measure, allowing patients to engage with physiotherapy and undergo preconditioning if arthroscopic interventions are still required.[39] However, this intervention should not delay definitive interventions in cases of clearly identified pathology, with delay risking progression of pathology and inferior outcomes.[40]

Limitations

This was a retrospective nonrandomized study. The sample size was arbitrary, but this should not have affected the findings. The review of MRI reports and relevant images was conducted by only 1 experienced clinical investigator, who was not blinded. This is a potential source of bias. The treatment was not blinded, although a sequential clinical cohort was reviewed, thus minimizing bias. The findings of this study were not correlated to postoperative clinical outcomes but could have contributed to the evidence; however, this was not the aim of this study. Additionally, it may have been of interest to correlate the resection with post-arthroscopy repeated MRI scans. This, however, posed further monetary and ethical implications and was not routinely undertaken. One of the main criticisms of our analysis is that the data are based on MRI scans with unreliable reference to the pelvic tilt. However, although this fact likely contributed to the accuracy of anterior over-coverage measurements by the AASA, it was unlikely to significantly influence the findings of comparison between the 3 interventions. We deliberately excluded the LCEA from this analysis because the aim was to determine the validity of the AASA in characterizing pincer-type lesions, which in turn were assumed to be more anterior rather than superior. However, the relative value of the LCEA and AASA merits further investigation.

Conclusions

Fluoroscopic EUS is accurate in characterizing FAI pathology. In addition, MRI is useful to diagnose or rule out non-FAI pathology, ascertain labral pathology, and outline hip alignment. These methods of preoperative planning are complementary.

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