The Lisbon Agreement on femoroacetabular impingement imaging — part 3 : imaging techniques

Reference:
Castro Miguel O., Mascarenhas Vasco V., Afonso P. Diana, Rego Paulo, Schmaranzer Florian, Sutter Reto, Kassarjian Ara, Sconfienza Luca, Dienst Michael, Ayeni Olufemi R., ...- The Lisbon Agreement on femoroacetabular impingement imaging — part 3 : imaging techniques
European radiology - ISSN 0938-7994 - 31(2021), p. 4652-4668
Full text (Publisher's DOI): https://doi.org/10.1007/S00330-020-07501-5
To cite this reference: https://hdl.handle.net/10067/1746680151162165141

"THE LISBON AGREEMENT ON FEMOROACETABULAR IMPINGEMENT IMAGING"

Part 3 – Imaging Techniques

ABSTRACT

Objectives: Imaging assessment of femoroacetabular impingement (FAI) remains controversial due to a lack of high-level evidence, leading to significant variability in patient management. Optimizing protocols and technical details is essential in FAI imaging, although challenging in clinical practice. The purpose of this agreement is to establish expert-based statements on FAI imaging, using formal consensus techniques driven by relevant literature review. Recommendations on the selection and use of imaging techniques for FAI assessment, as well as guidance on relevant radiographic and MRI classifications are provided.

Methods: The Delphi method was used to assess agreement and derive consensus among 30 panel members (musculoskeletal radiologists and orthopedic surgeons). Forty-four questions were agreed on, and recent relevant literature was circulated and classified in five major topics ("General issues", "Parameters and reporting", "Radiographic assessment", "MRI evaluation" and "Ultrasound") in order to produce answering statements. The level of evidence was assessed for all statements and panel members scored their level of agreement with each statement during 4 Delphi rounds. Either "group consensus", "group agreement" or "no agreement" was achieved.

Results: Forty-seven statements were generated and group consensus was reached for 45. Twenty-two statements pertaining to "Imaging techniques" were generated. Eight statements on "Radiographic assessment" and 12 statements on "MRI evaluation" gained consensus. No agreement was reached for the 2 "Ultrasound" related statements.

Conclusion: The first international consensus on FAI imaging was developed. Researchers and clinicians working with FAI and hip-related pain may use these recommendations to guide, develop and implement comprehensive, evidence-based imaging protocols and classifications.

Key Points

- Radiographic evaluation is recommended for the initial assessment of FAI, while MRI with a dedicated protocol is the gold standard imaging technique for the comprehensive evaluation of this condition.
- The MRI protocol for FAI evaluation should include unilateral small FOV with radial imaging, femoral torsion assessment and a fluid sensitive sequence covering the whole pelvis.
- The definite role of other imaging methods in FAI, such as ultrasound or CT is still not well defined.

Keywords

Hip; Femoroacetabular impingement; Musculoskeletal system; Imaging techniques; Guidelines; Delphi

Abbreviations

2D - two dimensional

3D - three dimensional

AI - acetabular index

AP - anteroposterior

CEA - center-edge angle

CT - computed tomography

CTA - CT arthrography

dMRA - direct magnetic resonance arthrography

ESSR - European Society of Musculoskeletal Radiology

FAI - femoroacetabular impingement

FHN - femoral head-neck

FOV - field-of-view

JSN - joint space narrowing

JSW - joint space width

KL - Kellgren and Lawrence

L-CEA - lateral center-edge angle

LOE - level of evidence

MRI - magnetic resonance imaging

MRA - magnetic resonance arthrography

OA - osteoarthritis

OARSI - Osteoarthritis Research Society International

SP - spinopelvic

INTRODUCTION

Femoroacetabular impingement (FAI) syndrome is a motion-related clinical disorder associated with the insidious onset of groin/hip pain, along with signs of limited motion and characteristic imaging findings[1, 2], resulting in abnormal contact between the proximal femur and the acetabular rim[1]. This conflicting motion has been associated with hip pain, functional impairment and may ultimately lead to premature osteoarthritis (OA) of the hip[3, 4].

While the presence of characteristic femoral (cam) and/or acetabular (pincer) morphologies on imaging is necessary to diagnose FAI syndrome[2], several imaging aspects of FAI remain largely unstandardized due to a lack of high-level evidence and little agreement amongst the radiology and orthopedic communities on which imaging modalities and parameters should be routinely used[5, 6], leading to significant variability amid practitioners and institutions. Furthermore, chondro-labral damage is heterogeneously assessed using unenhanced MRI, MR arthrography (MRA) and CT arthrography (CTA)[7-9], while different systems of classification of such damage exist[10, 11]. Additionally, given that signs of OA may preclude surgical treatment of FAI, several imaging modalities and classifications are used in an attempt to define the best surgical candidates, albeit with variable reliability[12-14].

Accordingly, there is a need for improvement and standardization of diagnostic and treatment algorithms in FAI. Collecting expert views in a structured and systematic manner is a valid method of identifying current medical opinions in areas where scientific evidence is conflicting or unavailable. The aim of this Delphi-based consensus, "The Lisbon Agreement on FAI Imaging", is thus to establish expert-based statements on imaging of FAI, by using formal techniques of consensus building among a group of specialists, driven by the results of relevant literature review. Protocols and technical parameters are the focus of this paper, which presents expert-based assertions on the selection and use of imaging techniques for FAI evaluation, as well as recommendations on relevant MRI and radiographic classifications. Other topics of the consensus initiative were discussed elsewhere.

METHODS

This paper is part of a multidisciplinary project aiming to establish expert-based consensus on FAI imaging, entitled 'The Lisbon agreement on FAI imaging'. Briefly, after project conception (VVM, MOC and PDA), the Delphi method was used to formally assess consensus in 4 rounds involving 30 radiology and orthopedic surgery experts. Panel members gathered in four meetings that sought to give feedback on the project status, discuss ideas and keep group members engaged. Panel members gave presentations on several consensus items during the ESSR 2019 annual meeting, held in Lisbon, Portugal.

Full details on these aspects, including participants, consensus technique, literature review, statement drafting, levels of evidence, final scoring and data analysis are provided as Supplementary material.

RESULTS AND DISCUSSION

A total of 30 experts (21 musculoskeletal radiologists and 9 orthopedic surgeons) were included. Of these, 26 participants completed the 4 rounds of the survey.

A total of 44 questions and 47 answering statements were generated and distributed among the topics “General issues” (9 statements), “Parameters and reporting” (16 statements), “Radiographic assessment” (8 statements), “MRI evaluation” (12 statements) and “Ultrasound” (2 statements). At the end of the Delphi process, 'group consensus' was obtained for 45 statements. Although level 2 evidence exists regarding the use of ultrasound in the evaluation of FAI, no agreement was reached for the 2 statements on this imaging technique, reflecting the non-established role of ultrasound in the diagnosis of FAI. Currently, its definite indication in FAI is to guide diagnostic and therapeutic hip joint injections[15]. More details on these aspects are provided as Supplementary material.

Due to the importance and scope of collected information, consensus items were combined in a three-part series for publication. In the current work, we report results concerning part 3 (Imaging Techniques), and include the topics “Radiographic assessment”, “MRI evaluation” and “Ultrasound” (Tables 1 and 2, Figure 1), followed by a summary of the panel’s discussion. The remaining items (General issues, Parameters and Reporting) will be published in part 2, while a selection of the most relevant statements is the subject of a first publication (“The Lisbon Agreement on Femoroacetabular Impingement Imaging. Part 1: Overview”, by Mascarenhas et al, submitted in December 2019, European Radiology).

Figure 1. Overview of the work-up of a suspected FAI patient, focusing on the role of different imaging modalities. Radiographs are used in first line assessment of FAI morphologies and signs of osteoarthritis (OA), while MRI provides a more comprehensive evaluation, including detailed bone morphology and evaluation of intra-articular soft tissue structures. Currently, the role of ultrasound is limited to guidance of hip injections.

AP: anteroposterior. w: with. wo: without.

Table 1. Panel statements on radiographs and MRI in FAI with evidence levels. All presented statements obtained group consensus. The listed levels of agreement represent the percentage of votes ≥8 on a 0-10 scale. AP: anteroposterior. FAI: femoroacetabular impingement. FHN: femoral head-neck. FOV: field-of-view. IQR: interquartile range. MRI: magnetic resonance imaging. L-CEA: lateral center-edge angle. LOE: level of evidence. Q1: 1st quartile. Q3: 3rd quartile. T: Tesla

Group	Type of statement	Statement	LOE	Median IQR (Q1-Q3) Level of agreement
RADIOGRAPHIC POSITIONING				
Should we use supine or standing radiographs of the pelvis?				
Radiographs	Technique	Supine radiographs are current clinical and research practice although evidence supports that standing radiographs may be preferable in the evaluation of hip pain, specifically in acetabular dysplasia and hip osteoarthritis.	2	**9** **2 (8-10)** **89%**

What are the relevant parameters to compare between supine and standing pelvis radiographs?				
Radiographs	Interpretation	Although most of the quantitative acetabular parameters are prone to positional variability, acetabular superior coverage (L-CEA and acetabular index) is relatively consistent between supine and standing positions. Conversely, measurements of anterior coverage and retroversion (cross-over sign, posterior wall sign) change with different positioning.	2	**10** **1.25 (8.75-10)** **89%**
RADIOGRAPHIC ASSESSMENT: LATERAL VIEWS AND SCOPE				
What is the optimal single lateral view to assess femoral morphology?				
Radiographs	Technique	The single optimal lateral radiograph is the Dunn 45° view as the femoral head-neck asphericity is most often localized in the anterosuperior region.	2	**10** **0.25 (9.75-10)** **96%**
Which combination of radiographic views is the best choice to diagnose Cam morphology?				
Radiographs	Technique	An AP pelvis radiograph and a Dunn 45° view are the best choice for the initial radiographic assessment of the FHN junction, as further radial imaging is usually performed when FAI is clinically suspected.	3	**10** **2 (8-10)** **93%**
Is it important to include a lumbar spine lateral radiographic view in the FAI series?				
Radiographs	Technique	There is no evidence to support additional lumbar imaging when FAI is suspected in clinical practice, although assessment of spinopelvic parameters and lumbar pathology are increasingly recognized as important in this setting.	3	**9** **2 (8-10)** **81%**
JOINT SPACE WIDTH AND OSTEOARTHRITIS CLASSIFICATION				
Measuring joint space width and narrowing: which radiographic view should be preferably used?				
Radiographs	Technique	An AP pelvic radiograph with a standardized technique should be preferably used for measuring joint space width and narrowing.	2	**10** **1.25 (8.75-10)** **89%**
Measuring joint space width: where should we do this measurement?				
Radiographs	Interpretation	Joint space width should be measured where maximal joint space narrowing is observed, preferably at the weight-bearing region of the hip joint.	2	**10** **1 (9-10)** **93%**
Should we use Tönnis or Kellgren and Lawrence classification in hip preserving surgery?				
Radiographs	Interpretation	Tönnis classification represents current clinical and research practice, although evidence supports that the "minimum joint space width" may be preferable compared to the other classification systems.	2	**10** **2 (8-10)** **96%**
MRI TECHNICAL CONSIDERATIONS				
Would you consider a 1.5T MRI scanner as the minimum acceptable field strength for the assessment of a patient with FAI?				
MRI	Technique	1.5T MRI should be considered the minimum recommended field strength for the evaluation of FAI.	5*	**10** **0 (10-10)** **96%**
What is the best technique to assess intra-articular lesions and provide support in treatment decision?				
MRI	Technique	Generally, direct MR arthrography is superior to non-contrast MRI. Emerging literature suggests that non-contrast 3T MRI is equivalent to 1.5T direct arthrography.	3	**10** **1.25 (8.75-10)** **96%**
Does the application of traction help in improving the accuracy of MRI?				
MRI	Technique	There is some evidence that MR arthrography with hip traction aids in the detection of cartilage delamination. Other applications of traction are still under investigation.	3	**10** **1.25 (8.75-10)** **86%**
MRI PROTOCOL				
Should radial imaging be routinely obtained in MRI studies for suspected FAI?				
MRI	Technique	Yes, radial imaging should be routinely obtained in FAI MRI studies.	3	**10** **0.25 (9.75-10)** **86%**

Is it possible to properly establish the extent of Cam morphology without radial imaging?				
MRI	Technique	No. Although radiographs can be used to detect Cam morphology, radial imaging is necessary to comprehensively assess the degree and extent of these morphologies by enabling a circumferential evaluation of the femoral head-neck junction.	3	**10** **1 (9-10)** **89%**
What is the minimum acceptable number of slices on a radial MRI sequence?				
MRI	Technique	The minimum acceptable number of slices in radial sequences should be 12 slices.	3	**10** **0 (10-10)** **89%**
Should the torsional profile of the femur be routinely included in MRI studies for suspected FAI?				
MRI	Technique	Yes. Femoral torsion should be routinely measured in MRI FAI studies, as this relevant osseous abnormality would be missed otherwise.	3	**10** **2 (8-10)** **93%**
Which MRI protocol should be used to assess the young patient with hip pain?				
MRI	Technique	In a young patient with hip pain, the MRI protocol should routinely include unilateral small FOV sequences and radial images, as well as femoral torsion assessment and a fluid sensitive sequence covering the whole pelvis.	5*	**10** **2 (8-10)** **93%**
LABRUM AND CARTILAGE ASSESSMENT				
How should a suspected labral lesion on imaging be reported?				
MRI	Interpretation	Although several classifications and grading systems have been proposed for labral lesions, there is no outcome-based evidence to support the use of a specific classification/grading. Description of location, configuration and extent of labral lesions may be clinically useful.	2	**10** **1 (9-10)** **100%**
How to distinguish between labral lesions and labral changes often seen in asymptomatic individuals without FAI?				
MRI	Interpretation	Intrasubstance labral degeneration, labral-chondral separation and to some degree intrasubstance tears are common in asymptomatic individuals without FAI. Labral tears should only be considered relevant in conjunction with patient history and clinical examination.	3	**10** **1.25 (8.75-10)** **89%**
How should cartilage lesions be reported in clinical routine?				
MRI	Interpretation	Although available evidence is limited on how cartilage lesions should be reported, description of the extent, location and pattern/grade is suggested.	5*	**10** **1.25 (8.75-10)** **93%**
Which articular lesions visible on MRI are associated with worse outcomes following FAI surgery?				
MRI	Interpretation	There is only sparse evidence on the prognostic value of intra-articular lesions detected on MRI: femoral and acetabular subchondral cysts, chondral damage exceeding 2 hours on the acetabular clock-face and central acetabular osteophytes are associated with worse outcomes following FAI surgery.	3	**9** **1.25 (8.75-10)** **96%**

* level of evidence 5 represents expert opinion

Table 2. Statements on the role of ultrasound in FAI, with evidence levels. The listed levels of agreement represent the percentage of votes ≥8 on a 0-10 scale. None of these statements obtained group agreement. FAI: femoroacetabular impingement. FHN: femoral head-neck. IQR: interquartile range. LOE: level of evidence. Q1: 1st quartile. Q3: 3rd quartile. US: ultrasound

Group	Type of statement	Statement	LOE	Median IQR (Q1-Q3) Level of agreement
What is the role of Ultrasound in FAI?				

US	Interpretation	Ultrasound can be used to measure the alpha angle in patients with suspected FAI, although limited to a single point of the FHN junction.	2	**5** **4 (2-6)** **22%**
US	Interpretation	Ultrasound may detect anterior superior labral lesions with moderate sensitivity and low specificity.	2	**5** **5.5 (2.5-8)** **33%**

RADIOGRAPHS

RADIOGRAPHIC POSITIONING

Statement: *Supine radiographs are current clinical and research practice although evidence supports that standing radiographs may be preferable in the evaluation of hip pain, specifically in acetabular dysplasia and hip osteoarthritis.*

Statement: *Although most of the quantitative acetabular parameters are prone to positional variability, acetabular superior coverage (L-CEA and acetabular index) is relatively consistent between supine and standing positions. Conversely, measurements of anterior coverage and retroversion (cross-over sign, posterior wall sign) change with different positioning.*

From supine to weight-bearing radiographs, significant positional pelvic changes occur[16-18]. Standing radiographs are typically associated with increased pelvis extension (i.e. posterior pelvic tilt or sacral verticalization)[16-19] and decreased measures of anterior coverage[16-18, 20]. Although some imaging parameters are prone to change between supine and standing positions due to pelvic extension, from the clinical standpoint acetabular measurements of superior coverage (the L-CEA, AI, extrusion index and Sharp angle) are relatively consistent between projections[16, 21]. On the other hand, measurements of anterior coverage and retroversion (anterior acetabular coverage, posterior acetabular coverage, cross-over sign, posterior wall sign and retroversion index) significantly change with pelvic tilt/rotation and consequently with different radiographic projections/positions[17, 19, 21] (Supplemental Table 1 and Supplemental Figure 1).

Supplemental Table 1. Influence of pelvic positioning (rotation and pelvic tilt) on radiographic hip parameters.
L-CEA: lateral center-edge angle.

No significant change with pelvic rotation and tilt	Relevant change with pelvic rotation and tilt
‣ L-CEA	‣ anterior acetabular coverage
‣ acetabular index	‣ posterior acetabular coverage
‣ extrusion index	‣ cross-over sign
‣ Sharp angle	‣ posterior wall sign
‣ craniocaudal coverage	‣ retroversion index

Supplemental Figure 1. AP radiographs of the pelvis in the same patient obtained in the supine (A) and weight-bearing (B) positions. In B the sacrum becomes more vertical and anterior acetabular coverage is reduced.

As such, in clinical entities where acetabular evaluation is essential, such as Pincer FAI and acetabular dysplasia, weight-bearing AP pelvic radiographs, although technically more challenging, have been advocated ideal since they reflect functional anatomical positioning[16, 18, 21]. The major drawback of this approach is related to the less straightforward comparison between standing preoperative radiographic assessment and fluoroscopy monitoring during surgery[22]. Additionally, most outcome studies and measurement thresholds are derived from supine AP radiographs. Surgeons and radiologists should be aware of these constraints[16, 21, 22] (Supplemental Table 2). Caution is warranted in *borderline* cases where small angular changes could be relevant to clinical decision-making. In such cases, a more comprehensive imaging evaluation should be undertaken.

In the assessment of hip OA, standing radiographs also seem to be preferable, although available data is not conclusive[23, 24].

Supplemental Table 2. Advantages of obtaining AP radiographs of the pelvis in the supine and standing positions.
JSN: joint space narrowing. JSW: joint space width. XR: radiograph.

Supine radiographs	Standing radiographs
▸ Technically easier to perform ▸ Easier to perform in obese and older patients ▸ Reproducible in the operating room ▸ Feasible in recent postoperative setting ▸ Most outcome studies derive from supine XR	▸ Adequate JSW and JSN measurement ▸ Allow functional assessment of acetabular morphology, version and coverage

RADIOGRAPHIC ASSESSMENT

a) Lateral hip views and Cam morphology assessment

Statement: *The single optimal lateral radiograph is the Dunn 45° view as the femoral head-neck asphericity is most often localized in the anterosuperior region.*

Statement: *An AP pelvis radiograph and a Dunn 45° view are the best choice for the initial radiographic assessment of the FHN junction, as further radial imaging is usually performed when FAI is clinically suspected.*

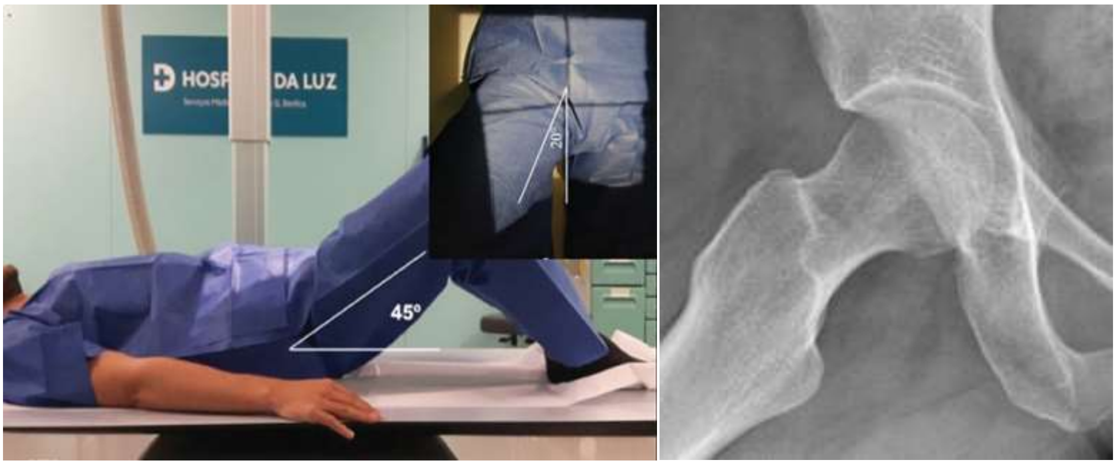
Presently, radiographs and MRI are the standard imaging modalities used to characterize hip pathomorphology and to plan treatment[2, 25]. For an initial diagnostic approach, AP pelvis and lateral radiographs[2, 6] have been traditionally used (Supplemental Table 3).

Supplemental Table 3. Summary of technical details and imaging purposes of several radiographic projections of the hip and pelvis.
AP: anteroposterior. ASIS: anterior superior iliac spines. FHN: Femoral head-neck. PS: pubic symphysis. α: alpha.

	POSITION	HIP FLEXION	KNEE FLEXION	FOOT POSITION	X-RAY BEAM	USEFULNESS
AP PELVIS	Supine/ Standing	0°	0°	15°-20° internal rotation	Centered to midpoint between the upper border of symphysis and a line connecting both ASIS	Basic radiographic evaluation for hip preserving surgery, total hip arthroplasty or trauma surgery. Neck-Shaft Angle; Acetabular Coverage/ Depth/Inclination; Head Sphericity; Joint Space Width
LAUENSTEIN	Supine + 45° Lateral Rotation to the side of interest	90°	45°	Parallel to the table	Hip-centered: vertically to the head of the Femur	Assessment of the anterosuperior coverage of the femoral head
FROG-LEG LATERAL	Supine	45° External Rotation	30°-40°	United plantar soles (if bilateral)	Pelvis-centered	Evaluation of the anterior and posterior FHN contour; Sphericity of the Femoral Head; Joint Congruency
CROSS TABLE LATERAL VIEW	Supine	0°	0°	15°-20° internal rotation	parallel to the table + oriented at 45° to the limb	Evaluation of the anterior and posterior FHN contour
FALSE PROFILE (LEQUESNE)	Standing + back tilted 65° to the “wall”	0°	0°	Parallel to the detector	Hip-centered	Assessment of the anterior coverage of the femoral head; quantification of posteroinferior joint space
DUCROQUET	Supine	90° flexion + 45° abduction	90°	45° abduction	Hip-centered	Assessment of the anterosuperior region of the FHN junction
DUNN 45°	Supine	45° + 20° abduction	90°	Neutral	Perpendicular and centered midway to the PS and the ASIS	Assessment of the anterosuperior region of the FHN junction; evaluation of the α angle
DUNN-RIPPSTEIN	Supine	90° flexion + 20° abduction	90°	Neutral	Perpendicular and centered midway to the PS and the ASIS	Assessment of the anterosuperior region of the FHN junction; Femoral antetorsion, anterior and posterior FHN contour

Femoral head-neck (FHN) asphericity in hips with FAI is usually localized anterosuperiorly[26, 27]. Although not unanimously accepted, these asphericities are usually best shown radiographically in a Dunn 45° view (hips in 45° of flexion and 20° of abduction) [28-30], which is the recommended lateral view by the consensus panel (Supplemental Figure 2).

Different authors have proposed other combinations of radiographic projections. Some have demonstrated that the use of a three-view series (AP pelvis, 45° Dunn, and frog-leg lateral; 45° Dunn, 90° Dunn and cross-table)[30] or a two-view series (Meyer lateral and 90° Dunn)[31] is ideal for the radiographic evaluation of Cam morphology. However, the alpha angle and head-neck offset measurements from these and other views were reported to describe no more than 50% of the overall variation in the shape of the proximal femur[31]. Given that the hip is a 3D structure, pre-arthritic hip conditions are generally best assessed with cross-sectional imaging[6].



Supplemental Figure 2. Dunn 45° radiograph. This is the recommended lateral view as a first line evaluation of proximal femoral morphologies, in combination with an AP view of the pelvis. It is obtained with the hip in 45° of flexion, 20° of abduction and neutral rotation.

b) Lateral lumbosacral views and spinopelvic parameters

Statement: *There is no evidence to support additional lumbar imaging when FAI is suspected in clinical practice, although assessment of spinopelvic parameters and lumbar pathology are increasingly recognized as important in this setting.*

Sagittal pelvic kinematics along with spinopelvic (SP) parameters have recently been studied for their effect on hip function, FAI[27, 32, 33], and hip replacement[34]. Variability in sagittal pelvic function may substantially influence impingement phenomena in the native and prosthetic hip[27, 32-34], but many of the spine-hip relations are still unexplored.

The consensus panel acknowledges that currently there isn't enough evidence to support routine additional lumbar imaging when FAI is suspected. However, when clinically deemed important, imaging evaluation of hip pathology may include a review of SP parameters and assessment for lumbar disease as a hip-pain mimicker, either with a lateral lumbosacral radiograph, or by CT/MRI of the entire pelvis with multiplanar reconstructions, instead of imaging only the hip of interest[27, 32, 33].

c) Joint space width and Osteoarthritis classification

***Statement**: An AP pelvic radiograph with a standardized technique should be preferably used for measuring joint space width and narrowing.*

***Statement**: Joint space width should be measured where maximal joint space narrowing is observed, preferably at the weight-bearing region of the hip joint.*

In hip OA, measurements of joint space width (JSW) and joint space narrowing (JSN) are currently the best way to assess structural progression and disease severity, respectively[24].

Radiographic measurements of JSN and JSW should be preferably carried out in a standing position (i.e. weight-bearing), which is regarded as more accurate and sensitive for JSN assessment in hips with at least moderate OA[23, 24, 35], although comparable results between standing and supine views have been reported[36]. AP pelvis and hip centered radiographs offer good and comparable precision for JSW assessment[24, 37].

JSW should be measured in the superior region of the hip joint. It is defined as the distance between the superior cortex of the femoral head and the acetabular sourcil (which is the articulating bright line of the superior acetabulum)[36]. The minimum JSW, which is the point of maximal narrowing in the superior region of the joint (Figure 2), is highly reproducible and has been recommended as the preferred primary structural endpoint in hip OA clinical trials[35].

Alternative projections (e.g. false profile) can evaluate JSW/JSN in locations other than the superior aspect of the joint and, when combined with an AP view, may increase sensitivity to detect structural alterations[38].

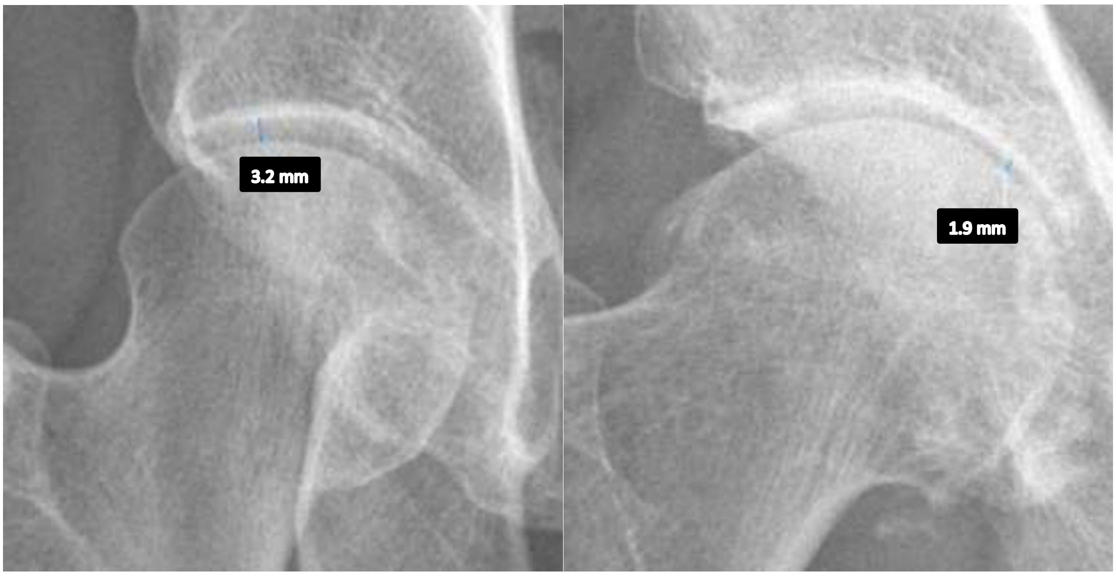


Figure 2. Examples of measurement of minimum joint space width. This measurement should be carried out in an AP pelvic or hip-centered radiograph, as the inter-bone distance at the point of maximal narrowing in the superior part of the joint space.

***Statement**: Tönnis classification represents current clinical and research practice, although evidence supports that the "minimum joint space width" may be preferable compared to the other classification systems.*

In the setting of hip OA, quantitative radiographic methods are mostly based on measurements of JSW. Semi-quantitative methods (Supplemental Table 4) identify and categorize different features like JSN, osteophytes, sclerosis and cyst formation, and include the Kellgren and Lawrence (KL) and Tönnis classifications, the Croft score and the Osteoarthritis Research Society International (OARSI) scores[39-41].

The Tönnis classification differentiates 3 grades of hip OA. This system is subjective and has been criticized for its unclear terminology and failure to discriminate overlapping parameters. Accordingly, it has been regarded as a poor method to assess early stages of OA[14, 42], implying that its routine use in surgical decision-making should be abandoned. Nevertheless, it is the most widely used radiographic semi-quantitative classification and outcome predictor in the setting of hip preservation research.

KL grading differentiates 4 grades of OA and has been regarded as the simplest method with excellent inter-reader variability[43]. However, it relies on a mixture of osteoarthritic features and it prejudges a unique sequence of events (osteophytes preceding JSN) which is not the sequence in which events always occur[44]. Additionally, several alternative versions of this scale have been reported[45], with different wording and descriptors, which may lead to inconsistent scoring and unreliable conclusions.

Although KL, OARSI stages and categorization of JSW have a similar predictive and construct validity, JSW appears to be more reproducible and sensitive to change[43].

Supplemental Table 4. The Tönnis and the Kellgren and Lawrence classifications of osteoarthritis.

	TÖNNIS	KELLGREN AND LAWRENCE
Grade 0	Normal	Normal

Grade 1	Increased sclerosis of the head and acetabulum, slight narrowing of the joint space, slight lipping at the joint margins	Doubtful narrowing of joint space and possible osteophytic lipping
Grade 2	Small cysts in the head or acetabulum, increasing narrowing of the joint space, moderate loss of sphericity of the head	Definite osteophytes and possible narrowing of joint space
Grade 3	Large cysts in the head or acetabulum, severe narrowing or obliteration of the joint space, severe deformity of the head, avascular necrosis	Moderate multiple osteophytes, definite narrowing of joint space, some sclerosis and possible deformity of bone ends
Grade 4	-	Large osteophytes, marked narrowing of joint space, severe sclerosis and definite deformity of bone ends

MRI

MRI is the gold standard imaging technique for hip and FAI assessment. The role of MRI in suspected FAI is summarized in Figure 3.

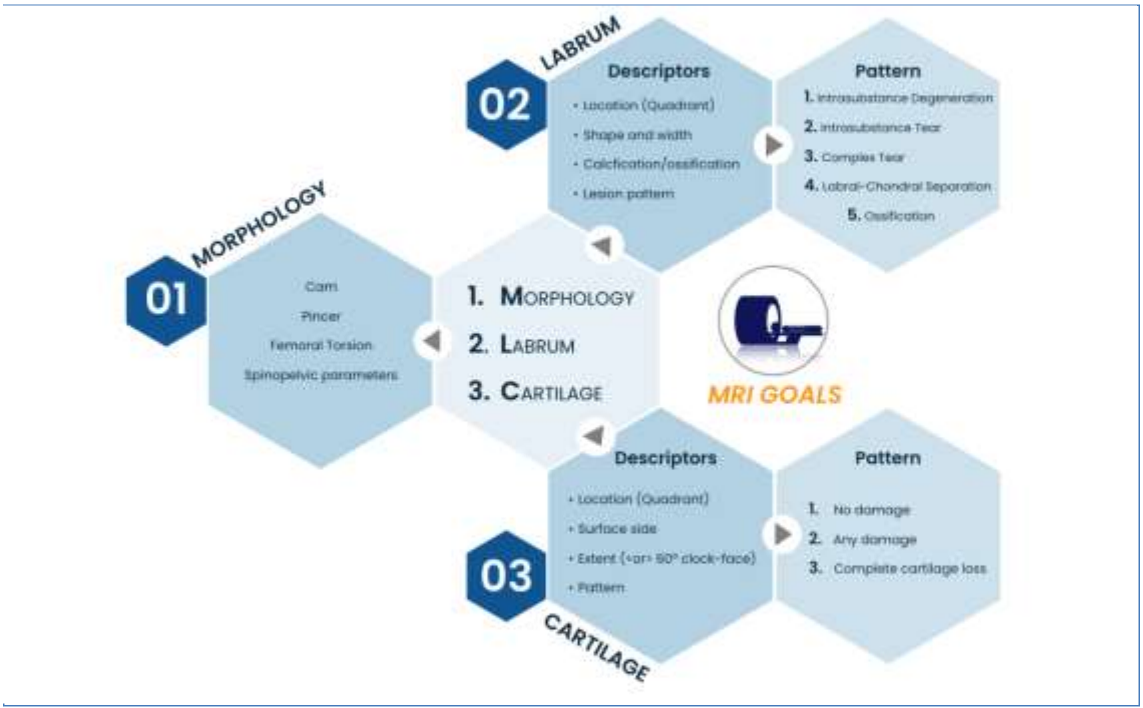


Figure 3. Imaging goals for MRI in FAI and recommended descriptors of chondrolabral damage. MRI is ideal to characterize bone morphology (particularly Cam morphology), address chondral/labral lesions and assess differential diagnosis.

TECHNICAL CONSIDERATIONS

Statement: *1.5T MRI should be considered the minimum recommended field strength for the evaluation of FAI.*

Statement: *Generally, direct MR arthrography is superior to non-contrast MRI. Emerging literature suggests that non-contrast 3T MRI is equivalent to 1.5T direct arthrography.*

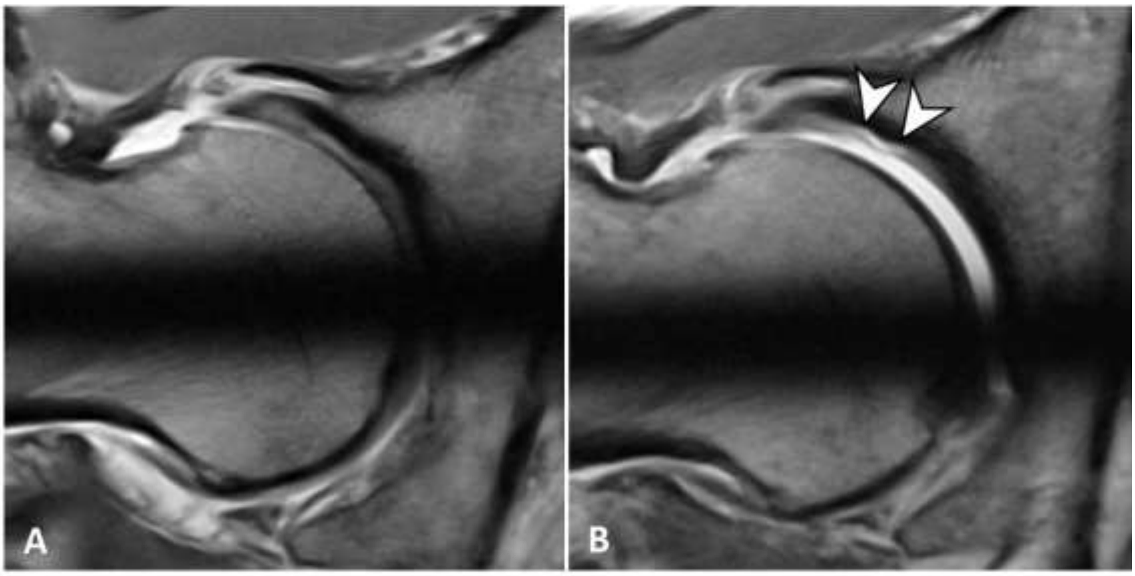
Statement: *There is some evidence that MR arthrography with hip traction aids in the detection of cartilage delamination. Other applications of traction are still under investigation.*

The role of imaging in treatment decision-making is directed mostly to confirmation and characterization of osseous morphologies, determination of chondro-labral damage severity[1, 2, 46] and differential diagnosis assessment (Figure 1). Radiographs can only indirectly assess articular cartilage damage, by depicting reduced JSW and secondary OA changes, while MRI, MRA and CTA may demonstrate focal/regional cartilage lesions despite minimal or absent radiographic findings. In cases of high-grade lesions, no significant advantage of either of the latter techniques has been demonstrated, as all are able to show severe/extensive chondral damage with relative accuracy, and thus influence the decision of surgical versus non-surgical management[1, 6, 47].

An MRI field strength of 1,5T should be the minimum to be used in FAI assessment[7, 8]. Unenhanced MRI and direct MRA (dMRA) are the techniques of choice for detection of hip chondro-labral lesions, although evidence indicates dMRA as the best technique to study intra-articular pathology[7-9]. 3T MRI was reportedly equivalent to 1.5T dMRA for diagnosing labral tears and cartilage delamination, but superior for acetabular cartilage defects. Additionally, 3T MRI demonstrated similar sensitivity to 3T dMRA in the detection of acetabular labral tears, although the latter is more sensitive for the detection of acetabular chondral lesions[7, 8, 48, 49].

Indirect MRA is generally not indicated. Literature is scarce comparing indirect MRA to MRI, although it shows less overall accuracy of indirect MRA when compared to dMRA[7, 8].

There is some evidence that dMRA with hip traction aids in the detection of cartilage delamination both at 1.5T and 3T, by uncovering cartilage flaps that are usually less visible on the reduced femoral head (Supplemental Figure 3). There is no data regarding the use of hip traction during non-arthrographic MRI and only scant data regarding traction with indirect MRA for evaluating labral tears[11, 50]. It is still unclear whether traction at hip MRA should be used routinely and, if so, whether images should be obtained without and/or with traction.



Supplemental Figure 3. 32-year-old man with Cam FAI who was referred for preoperative MR arthrography of the hip for assessment of intra-articular lesions. Radial PD-w images at 3T were obtained (A) without traction and (B) with the application of leg traction. (A) Without traction the articular cartilage layers cannot be differentiated and no cartilage damage is evident. (B) After joint distraction with 18 kg, contrast agent enters the central joint compartment and undermines the delaminated acetabular cartilage (arrowheads).

Unenhanced CT is not as well established in FAI imaging. Although volumetric CT is excellent at depicting osseous morphologies, assessing osteoarthritic changes[6, 51] and may be used in virtual range of motion 3D simulation studies[6, 51, 52], it is unable to detect chondrolabral changes and is associated with significant radiation exposure in this frequently young population. While CT is sometimes ordered in conjunction with MRI to assess both bony and soft tissue structures, along with different authors reporting on its use for pre-surgical planning[6, 51, 53], volumetric MRI may be used as a radiation-free all-in-one alternative, helping to reduce costs and time spent in the workup of these patients[6, 51].

PROTOCOL

***Statement**: Radial imaging should be routinely obtained in FAI MRI studies.*

***Statement**: Although radiographs can be used to detect Cam morphology, radial imaging is necessary to comprehensively assess the degree and extent of these morphologies by enabling a circumferential evaluation of the femoral head-neck junction.*

***Statement**: The minimum acceptable number of slices in radial sequences should be 12 slices.*

Radial MRI images rotating around the femoral neck axis should be included in all suspected FAI cases, as they allow depiction of FAI morphologies which are typically located anterosuperiorly[6, 27, 54]. Radiographs may help diagnose Cam FAI, but cannot exclude the presence of Cam morphology and underestimate its severity[55]. A recent study confirmed this and noted the highest correlation between increased alpha angle measured on radial MRI and the Dunn 45° radiographic view, as this view represents the anterosuperior portion of the FHN junction[56]. Thus, either radial proton density weighted sequences along the axis of the femoral neck (providing higher resolution images)[6, 52] or radial reconstructions from 3D acquisitions[26, 54] should be used, to precisely quantify the asphericity of the FHN junction. Although currently used software assisted analysis allows for circumferential evaluation of the FHN junction[26, 27, 54], most studies have used at least 12 radial slices[57, 58] (which is easier to apply in clinical practice). Radial sequences seem to have less added value for assessing the acetabulum and/or labrum[59].

***Statement**: Femoral torsion should be routinely measured in MRI FAI studies, as this relevant osseous abnormality would be missed otherwise.*

There is consistent evidence that abnormal femoral antetorsion is one of the three major osseous abnormalities involved in the development of FAI[25], with a substantial number of patients with abnormally high or low femoral torsion. Several independent authors concluded that femoral torsional profile measurements should be routinely included in the imaging workup of FAI patients[60, 61]. To date, still, no published systematic reviews or meta-analysis are available on this topic.

***Statement**: In a young patient with hip pain the MRI protocol should routinely include unilateral small FOV sequences and radial images, as well as femoral torsion assessment and a fluid-sensitive sequence covering the whole pelvis.*

While evidence is lacking regarding the ideal hip MRI protocol, sequence details or comparison between protocols, the following sequences are recommended for the assessment of a young patient with hip pain (Figure 4):

1. unilateral, small FOV, high-resolution sequences of the symptomatic hip[6, 25, 28, 58];

2. radial imaging (either direct acquisition or 3D reformats);

3. fast axial sequence of the femoral condyles and femoral neck, to assess femoral torsion;

4. a fluid-sensitive sequence with a large FOV covering the whole pelvis, to screen for soft-tissue and bone marrow edema beyond the hip.

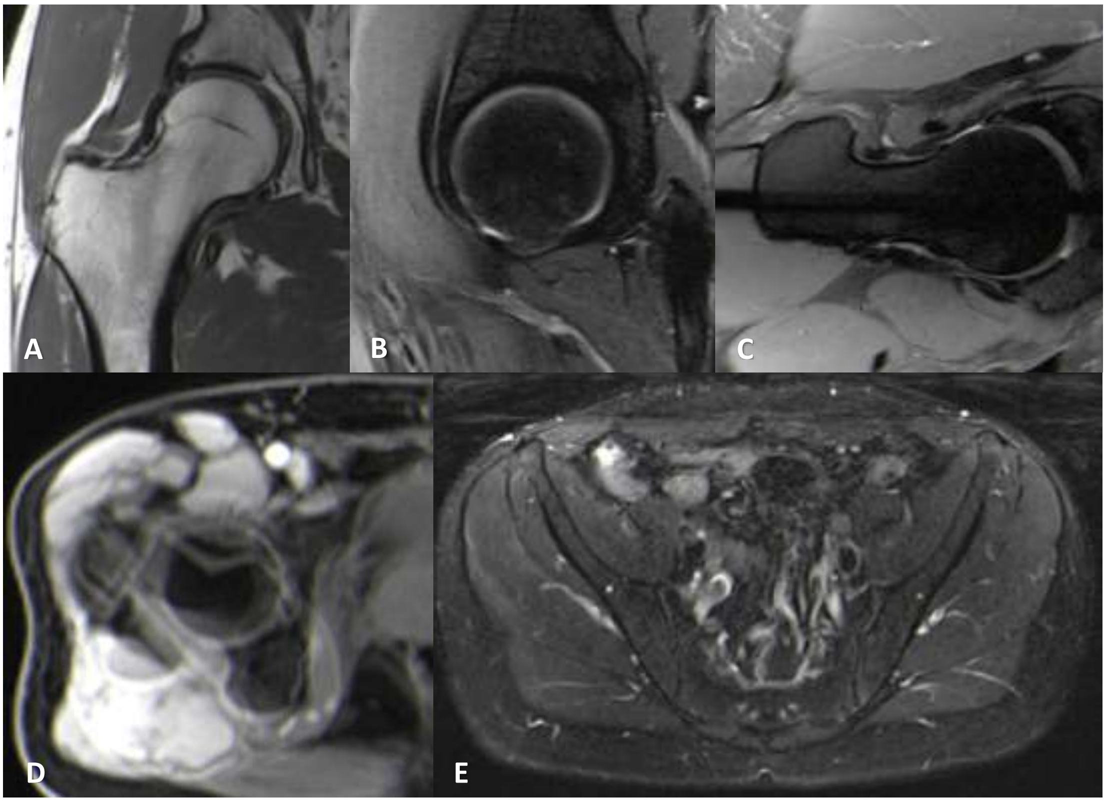


Figure 4. Sequences that should be incorporated in the proposed MRI protocol for the assessment of suspected FAI. Unilateral hip proton-density 2D sequences, with or without fat-suppression, in the coronal (A), sagittal (B) and axial oblique planes, are used for hip anatomic assessment. Radial imaging, either a 2D proton-density sequence (C) or reformats from a 3D acquisition, is performed to evaluate the morphology of the femoral head-neck junction. For assessing femoral torsion, measurements can be accomplished by superimposing different slices on a single image with postprocessing software (D). A 2D axial large-FOV fluid-sensitive sequence of the pelvis (E) is used to screen for possible differential diagnosis.

LABRUM AND CARTILAGE ASSESSMENT

a) Labrum

Statement: *Although several classifications and grading systems have been proposed for labral lesions, there is no outcome-based evidence to support the use of a specific classification/grading. Description of location, configuration and extent of labral lesions may be clinically useful.*

Statement: *Intrasubstance labral degeneration, labral-chondral separation and to some degree intrasubstance tears are common in asymptomatic individuals without FAI. Labral tears should only be considered relevant in conjunction with patient history and clinical examination.*

Several surgical and MRI-based classifications for the description of labrum lesions have been proposed[10, 62]. Currently, no evidence supports the use of a specific description of labral injury based on treatment outcomes. Due to the weak agreement between these classifications, imaging assessment of the acetabular labrum may instead focus on an accurate description, including location, configuration and extent of labral tears and associated cartilage and osseous changes[63] (Table 3, Figure 5). Such description can conceptually be applied to any MRI examination with the above-mentioned technique and protocol MR recommendations.

Table 3. Recommended descriptors of labral injury, based on inferential evidence[7, 11, 48].

PARAMETERS	DESCRIPTION
Location/Extent	Quadrant description
Shape and Width	Triangular/round; mm
Calcifications and Ossifications	Location and Size
Lesion patterns	1. Intrasubstance labrum degeneration
	2. Intrasubstance labral tear
	3. Labral-chondral separation (= labral detachment)
	4. Complex labral tear (both intrasubstance tear and labral-chondral separation)
	5. Labral ossification

Several studies report on intrasubstance labral degeneration, labral-chondral separation and some intrasubstance tears, in up to 68% of asymptomatic individuals[64, 65]. Labral tears should only be considered relevant with an adequate patient history and suggestive clinical examination.

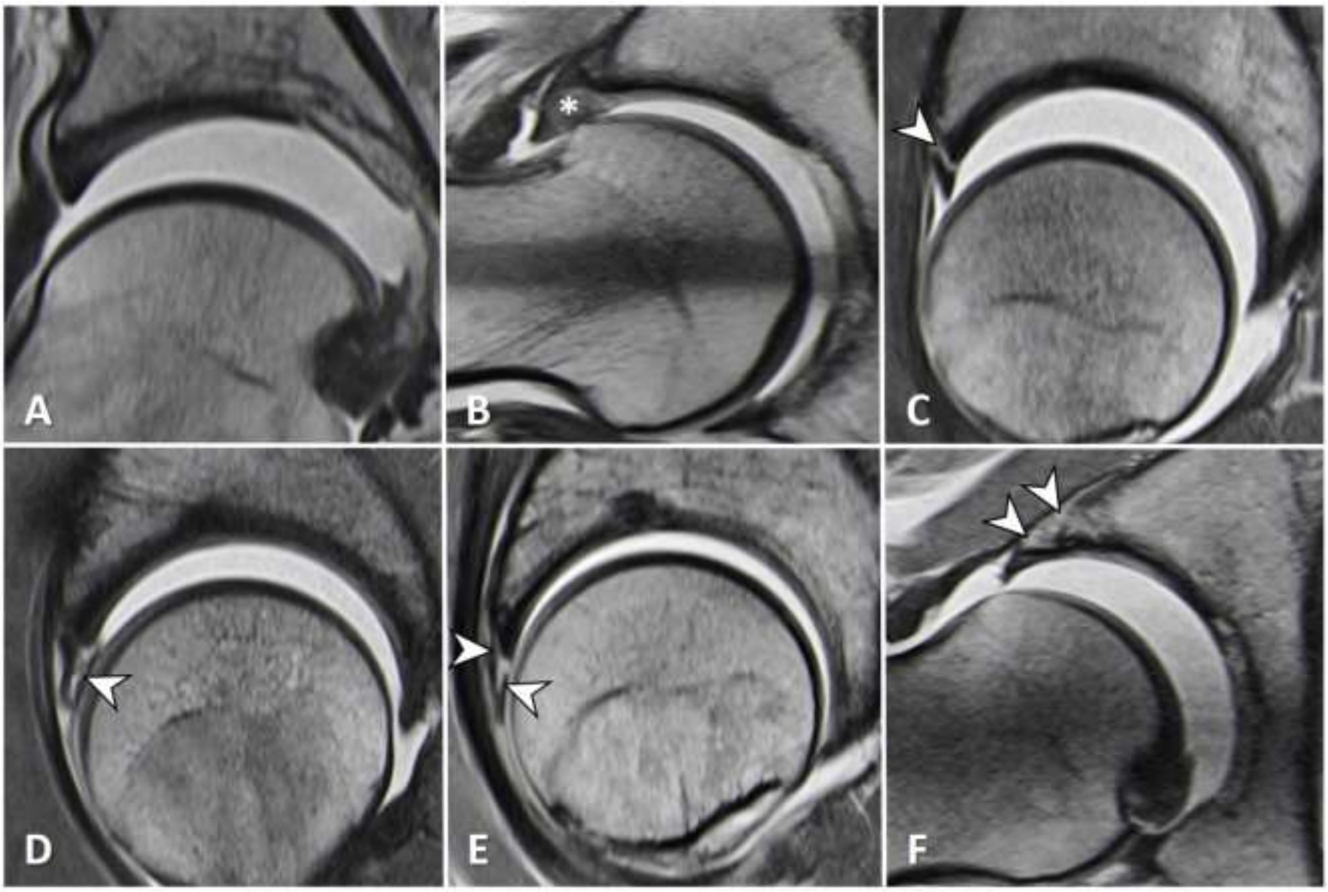


Figure 5. Classification of labrum damage patterns (traction MRA). (A) Normal labrum; (B) Intrasubstance labrum degeneration; (C) Labral-chondral separation (=labral detachment); (D) Intrasubstance labrum tear; (E) Complex labrum tear (Labral-chondral separation and intrasubstance labrum tear); (F) Labral ossification.

b) Cartilage

***Statement**: Although available evidence is limited on how cartilage lesions should be reported, description of the extent, location and pattern/grade is suggested.*

Information obtained on hip arthroscopy, during direct observation and probing, is necessarily more comprehensive than the one appreciated on a static examination such as MRI. Consequently, unifying MRI-arthroscopic classifications are deemed to be inconsistent and prone to error. Additionally, there is only outcome-based evidence supporting the description of the extent of cartilage damage by MRI, while only inferential evidence is available for the remaining features. Nevertheless, description of the location, surface and pattern/grade is recommended by the panel members, as it is consistently feasible when using the proposed MRI protocols and technique (Table 4, Figure 6).

The extent of cartilage damage evaluated by MRA is reportedly an independent prognostic factor for long-term outcome of FAI surgery (worse if greater than 60° - see below)[66]. In the presence of extensive cartilage loss some surgeons may choose not to perform corrective FAI surgery.

The pattern of cartilage lesion can also affect surgical planning, including the technique and timing of cartilage repair (e. g. abrasion/microfracture vs. autologous cartilage transplantation) and potential concomitant intra-articular and additional extra-articular osseous procedures.

Location also has diagnostic, prognostic and surgical planning implications. Typically located lesions support a FAI mechanism and corresponding treatment, while atypically located lesions may support other etiologies (e.g. trauma, overuse)[58]. Femoral cartilage damage is a poor prognostic factor, is indicative for progressive joint degeneration, and may only be accessed via open surgery and not via hip arthroscopy[67, 68]. Additionally, posterior lesions are difficult to access arthroscopically[69].

Table 4. Recommended descriptors of cartilage lesions on a hip MRI study.

PARAMETERS	DESCRIPTION
LOCATION **	Quadrant description
SURFACE SIDE **	Acetabular or femoral
EXTENT *	Any MRI cartilage damage should be defined as: a) extending <2 'hours' (i.e. 60°) on the clock-face b) extending >2 'hours' (i.e. 60°) on the clock-face
PATTERN **	A. 3 grades: 1. no damage 2. any cartilage damage 3. complete cartilage loss B. Other descriptors: i. peripheral (chondrolabral junction) vs. central

	ii. for grade 2 lesions (any cartilage damage) if possible add details, such as: 'superficial cartilage damage', 'percentage of cartilage damage depth' or 'cartilage delamination'

* Recommendations based on outcome evidence.
**Recommendations based on inferential evidence.

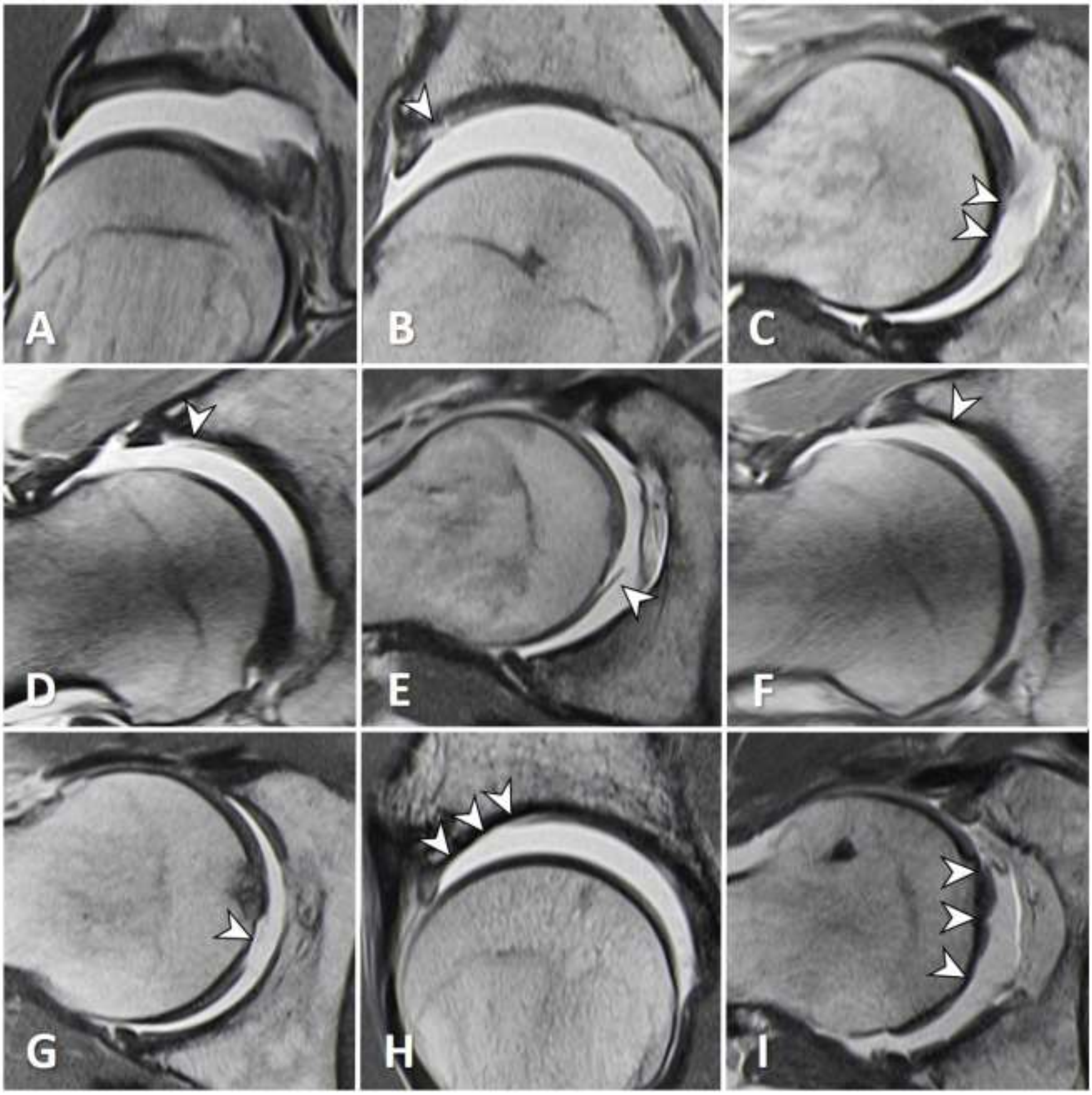


Figure 6. Classification of femoroacetabular cartilage damage patterns (traction MRA). (A) **Grade 1**: no damage (normal cartilage thickness). **Grade 2**: any cartilage damage, focal (B) acetabular and (C) femoral partial thickness cartilage lesion. **Grade 2**: any cartilage damage, (D) acetabular cartilage delamination involving the chondro-labral junction and (E) femoral cartilage delamination. **Grade 3**: complete cartilage

loss, focal full-thickness (F) acetabular and (G) femoral cartilage lesion. **Grade 3**: complete cartilage loss, diffuse full-thickness (H) acetabular and (I) femoral cartilage lesion.

***Statement**: There is only sparse evidence on the prognostic value of intra-articular lesions detected on MRI: femoral and acetabular subchondral cysts, chondral damage exceeding 2 hours on the acetabular clock-face and central acetabular osteophytes are associated with worse outcomes following FAI surgery.*

MRI may aid in treatment decision as it can help to distinguish which patients would benefit from FAI surgery. Although still limited, there is emerging evidence on the prognostic value of intra-articular lesions detected on MRI. Femoral and acetabular subchondral cysts are associated with increased rates of clinical failure at short- and long-term[70, 71]. Cartilage damage exceeding 2h/60° on the acetabular clock-face and central acetabular osteophytes are poor prognostic factors and are associated with higher rates of clinical failure 10 years after FAI surgery[66].

As most of these lesions might go unrecognized in radiographs, MRI/MRA should be increasingly considered in candidates to hip preserving surgery and included in treatment algorithms[66]. Additionally, a high prevalence of sacroiliac joint abnormalities (25.2%) and a low prevalence (1.8%-2.6%) of pubic symphysis abnormalities were reported on imaging in FAI patients. Importantly, these patients may demonstrate significantly inferior clinical outcomes and persistent postoperative pain after FAI treatment[72].

CONCLUSION

In conclusion, the first international, multidisciplinary Delphi-based consensus for imaging of FAI was developed. We critically reviewed the available evidence, the roles and limitations of each imaging technique, and highlighted recommended protocols and classifications. The resulting consensus can help practitioners working with hip-related pain to reduce variability in preoperative, intraoperative and postoperative practices, in addition to guide, develop and implement comprehensive, evidence-based imaging protocols and classifications for future research and clinical management of FAI.

REFERENCES

1. Ganz R, Parvizi J, Beck M, et al (2003) Femoroacetabular impingement: a cause for osteoarthritis of the hip. Clin Orthop Relat Res 112–120. doi: 10.1097/01.blo.0000096804.78689.c2

2. Griffin DR, Dickenson EJ, O'Donnell J, et al (2016) The Warwick Agreement on femoroacetabular impingement syndrome (FAI syndrome): an international consensus statement. British Journal of Sports Medicine 50:1169–1176. doi: 10.1136/bjsports-2016-096743

3. Agricola R, Heijboer MP, Bierma-Zeinstra SMA, et al (2013) Cam impingement causes osteoarthritis of the hip: a nationwide prospective cohort study (CHECK). Ann Rheum Dis 72:918–923. doi: 10.1136/annrheumdis-2012-201643

4. Beaulé PE, Grammatopoulos G, Speirs A, et al (2018) Unravelling the Hip Pistol Grip / CAM Deformity: Origins to Joint Degeneration. J Orthop Res. doi: 10.1002/jor.24137

5. Kassarjian A (2019) Hip Hype: FAI Syndrome, Amara's Law, and the Hype Cycle. Semin Musculoskelet Radiol. doi: 10.1055/s-0039-1677695

6. Mascarenhas VV, Ayeni OR, Egund N, et al (2019) Imaging Methodology for Hip Preservation: Techniques, Parameters, and Thresholds. Semin Musculoskelet Radiol 23:197–226. doi: 10.1055/s-0039-1688714

7. Saied AM, Redant C, El-Batouty M, et al (2017) Accuracy of magnetic resonance studies in the detection of chondral and labral lesions in femoroacetabular impingement: systematic review and meta-analysis. BMC Musculoskelet Disord 18:83. doi: 10.1186/s12891-017-1443-2

8. Smith TO, Simpson M, Ejindu V, Hing CB (2012) The diagnostic test accuracy of magnetic resonance imaging, magnetic resonance arthrography and computer tomography in the detection of chondral lesions of the hip. Eur J Orthop Surg Traumatol 23:335–344. doi: 10.1007/s00590-012-0972-5

9. Sutter R, Zubler V, Hoffmann A, et al (2014) Hip MRI: How Useful Is Intraarticular Contrast Material for Evaluating Surgically Proven Lesions of the Labrum and Articular Cartilage? AJR Am J Roentgenol 202:160–169. doi: 10.2214/AJR.12.10266

10. Czerny C, Hofmann S, Neuhold A, et al (1996) Lesions of the acetabular labrum: accuracy of MR imaging and MR arthrography in detection and staging. Radiology 200:225–230. doi: 10.1148/radiology.200.1.8657916

11. Schmaranzer F, Klauser A, Kogler M, et al (2014) Diagnostic performance of

direct traction MR arthrography of the hip: detection of chondral and labral lesions with arthroscopic comparison. Eur Radiol. doi: 10.1007/s00330-014-3534-x

12. Philippon MJ, Briggs KK, Carlisle JC, Patterson DC (2013) Joint Space Predicts THA After Hip Arthroscopy in Patients 50 Years and Older. Clin Orthop Relat Res 471:2492–2496. doi: 10.1007/s11999-012-2779-4

13. Skendzel JG, Philippon MJ, Briggs KK, Goljan P (2014) The Effect of Joint Space on Midterm Outcomes After Arthroscopic Hip Surgery for Femoroacetabular Impingement. The American Journal of Sports Medicine 42:1127–1133. doi: 10.1177/0363546514526357

14. Valera M, Ibañez N, Sancho R, Tey M (2015) Reliability of To¨nnis classification in early hip arthritis: a useless reference for hip-preserving surgery. Arch Orthop Trauma Surg 136:27–33. doi: 10.1007/s00402-015-2356-x

15. Khan W, Khan M, Alradwan H, et al (2015) Utility of Intra-articular Hip Injections for Femoroacetabular Impingement: A Systematic Review. Orthopaedic Journal of Sports Medicine. doi: 10.1177/2325967115601030

16. Troelsen A, Jacobsen S, Rømer L, Søballe K (2008) Weightbearing Anteroposterior Pelvic Radiographs are Recommended in DDH Assessment. Clin Orthop Relat Res 466:813–819. doi: 10.1007/s11999-008-0156-0

17. Pullen WM, Henebry A, Gaskill T (2014) Variability of Acetabular Coverage Between Supine and Weightbearing Pelvic Radiographs. The American Journal of Sports Medicine 42:2643–2648. doi: 10.2106/JBJS.D.02043

18. Fuchs-Winkelmann S, Peterlein C-D, Tibesku CO, Weinstein SL (2008) Comparison of Pelvic Radiographs in Weightbearing and Supine Positions. Clin Orthop Relat Res 466:809–812. doi: 10.1007/s11999-008-0124-8

19. Ross JR, Nepple JJ, Philippon MJ, et al (2014) Effect of Changes in Pelvic Tilt on Range of Motion to Impingement and Radiographic Parameters of Acetabular Morphologic Characteristics. The American Journal of Sports Medicine 42:2402–2409. doi: 10.1177/0363546514541229

20. Ross JR, Tannenbaum EP, Nepple JJ, et al (2015) Functional Acetabular Orientation Varies Between Supine and Standing Radiographs: Implications for Treatment of Femoroacetabular Impingement. Clin Orthop Relat Res 473:1267–1273. doi: 10.1007/s11999-014-4104-x

21. Tannast M, Fritsch S, Zheng G, et al (2014) Which Radiographic Hip Parameters Do Not Have to Be Corrected for Pelvic Rotation and Tilt? Clin Orthop Relat Res. doi: 10.1007/s11999-014-3936-8

22. Kosuge D, Cordier T, Solomon LB, Howie DW (2014) Dilemmas in imaging for peri-acetabular osteotomy: the influence of patient position and imaging

technique on the radiological features of hip dysplasia. The Bone & Joint Journal 96-B:1155–1160. doi: 10.1302/0301-620X.96B9.34269

23. Conrozier T, Lequesne MG, Tron AM, et al (1997) The effects of position on the radiographic joint space in osteoarthritis of the hip. Osteoarthritis and Cartilage 5:17–22.

24. Lane NE, Hochberg MC, Nevitt MC, et al (2015) OARSI Clinical Trials Recommendations: Design and conduct of clinical trials for hip osteoarthritis. Osteoarthritis and Cartilage 23:761–771. doi: 10.1016/j.joca.2015.03.006

25. Sutter R, Pfirrmann CWA (2017) Update on Femoroacetabular Impingement: What Is New, and How Should We Assess It? Semin Musculoskelet Radiol 21:518–528. doi: 10.1055/s-0037-1606141

26. Mascarenhas VV, rego P, Dantas P, et al (2017) Cam deformity and the omega angle, a novel quantitative measurement of femoral head-neck morphology: a 3D CT gender analysis in asymptomatic subjects. Eur Radiol 27:2011–2023. doi: 10.1007/s00330-016-4530-0

27. Mascarenhas VV, Rego PA, Dantas P, et al (2018) Can We Discriminate Symptomatic Hip Patients From Asymptomatic Volunteers Based on Anatomic Predictors? A 3-Dimensional Magnetic Resonance Study on Cam, Pincer, and Spinopelvic Parameters. The American Journal of Sports Medicine 46:3097–3110. doi: 10.1177/0363546518800825

28. Domayer SE, Ziebarth K, Chan J, et al (2011) Femoroacetabular cam-type impingement: diagnostic sensitivity and specificity of radiographic views compared to radial MRI. European Journal of Radiology 80:805–810. doi: 10.1016/j.ejrad.2010.10.016

29. Meyer DC, Beck M, Ellis T, et al (2006) Comparison of Six Radiographic Projections to Assess Femoral Head/Neck Asphericity. Clin Orthop Relat Res. doi: 10.1097/01.blo.0000201168.72388.24

30. ANCHOR Study Group, Nepple JJ, Martel JM, et al (2012) Do Plain Radiographs Correlate With CT for Imaging of Cam-type Femoroacetabular Impingement? Clin Orthop Relat Res 470:3313–3320. doi: 10.1007/s11999-012-2510-5

31. Atkins PR, Shin Y, Agrawal P, et al (2018) Which Two-dimensional Radiographic Measurements of Cam Femoroacetabular Impingement Best Describe the Three-dimensional Shape of the Proximal Femur? Clin Orthop Relat Res 1. doi: 10.1097/CORR.0000000000000462

32. Ng KCG, Lamontagne M, Jeffers JRT, et al (2018) Anatomic Predictors of Sagittal Hip and Pelvic Motions in Patients With a Cam Deformity. The American Journal of Sports Medicine 2014:036354651875515. doi: 10.1016/j.arthro.2016.01.011

33. Grammatopoulos G, Speirs AD, Ng KCG, et al (2018) Acetabular and spino-pelvic

morphologies are different in subjects with symptomatic cam femoro-acetabular impingement. J Orthop Res 36:1840–1848. doi: 10.1002/jor.22375

34. Rivière C, Lazennec JY, Van Der Straeten C, et al (2017) The influence of spine-hip relations on total hip replacement: A systematic review. Orthop Traumatol Surg Res 103:559–568. doi: 10.1016/j.otsr.2017.02.014

35. Altman RD, Bloch DA, Dougados M, et al (2004) Measurement of structural progression in osteoarthritis of the hip: the Barcelona consensus group11Supported by an unrestricted grant from NEGMA-LERADS Laboratories. Osteoarthritis and Cartilage 12:515–524. doi: 10.1016/j.joca.2004.04.004

36. Auleley GR, Rousselin B, Ayral X, et al (1998) Osteoarthritis of the hip: agreement between joint space width measurements on standing and supine conventional radiographs. Ann Rheum Dis 57:519–523.

37. Conrozier T, Lequesne M, Favret H, et al (2001) Measurement of the radiological hip joint space width. An evaluation of various methods of measurement. Osteoarthritis and Cartilage 9:281–286. doi: 10.1053/joca.2000.0386

38. Maheu E, Cadet C, Marty M, et al (2005) Reproducibility and sensitivity to change of various methods to measure joint space width in osteoarthritis of the hip: a double reading of three different radiographic views taken with a three-year interval. Arthritis Res Ther 7:R1375–85. doi: 10.1186/ar1831

39. Croft P, Cooper C, Wickham C, Coggon D (1990) Defining osteoarthritis of the hip for epidemiologic studies. Am J Epidemiol 132:514–522.

40. Altman RD, Gold GE (2007) Atlas of individual radiographic features in osteoarthritis, revised. Osteoarthritis and Cartilage 15:A1–A56. doi: 10.1016/j.joca.2006.11.009

41. Kellgren JH, LAWRENCE JS (1957) Radiological assessment of osteo-arthrosis. Ann Rheum Dis 16:494–502.

42. Nepple JJ, Martell JM, Kim YJ, et al (2014) Interobserver and Intraobserver Reliability of the Radiographic Analysis of Femoroacetabular Impingement and Dysplasia Using Computer-Assisted Measurements. The American Journal of Sports Medicine 42:2393–2401. doi: 10.1177/0363546514542797

43. Gossec L, Jordan JM, Lam M-A, et al (2009) Comparative evaluation of three semi-quantitative radiographic grading techniques for hip osteoarthritis in terms of validity and reproducibility in 1404 radiographs: report of the OARSI-OMERACT Task Force. Osteoarthritis and cartilage / OARS, Osteoarthritis Research Society 17:182–187. doi: 10.1016/j.joca.2008.06.009

44. Spector TD, Cooper C (1993) Radiographic assessment of osteoarthritis in population studies: whither Kellgren and Lawrence? Osteoarthritis and Cartilage 1:203–206.

45. Schiphof D, Boers M, Bierma-Zeinstra SMA (2008) Differences in descriptions of Kellgren and Lawrence grades of knee osteoarthritis. Ann Rheum Dis 67:1034–1036. doi: 10.1136/ard.2007.079020

46. Nepple JJ, Prather H, Trousdale RT, et al (2013) Clinical diagnosis of femoroacetabular impingement. J Am Acad Orthop Surg 21 Suppl 1:S16–9. doi: 10.5435/JAAOS-21-07-S16

47. Ayeni OR, Wong I, Chien T, et al (2012) Surgical Indications for Arthroscopic Management of Femoroacetabular Impingement. Arthroscopy: The Journal of Arthroscopic & Related Surgery 28:1170–1179. doi: 10.1016/j.arthro.2012.01.010

48. Crespo-Rodríguez AM, De Lucas-Villarrubia JC, Pastrana-Ledesma M, et al (2017) The diagnostic performance of non-contrast 3-Tesla magnetic resonance imaging (3-T MRI) versus 1.5-Tesla magnetic resonance arthrography (1.5-T MRA) in femoro-acetabular impingement. European Journal of Radiology 88:109–116. doi: 10.1016/j.ejrad.2016.12.031

49. Smith TO, Hilton G, Toms AP, et al (2010) The diagnostic accuracy of acetabular labral tears using magnetic resonance imaging and magnetic resonance arthrography: a meta-analysis. Eur Radiol. doi: 10.1007/s00330-010-1956-7

50. Llopis E, Cerezal L, Kassarjian A, et al (2008) Direct MR arthrography of the hip with leg traction: feasibility for assessing articular cartilage. AJR Am J Roentgenol 190:1124–1128. doi: 10.2214/AJR.07.2559

51. Samim M, Eftekhary N, Vigdorchik JM, et al (2019) 3D-MRI versus 3D-CT in the evaluation of osseous anatomy in femoroacetabular impingement using Dixon 3D FLASH sequence. Skeletal Radiol 48:429–436. doi: 10.1007/s00256-018-3049-7

52. Mascarenhas VV, Caetano A (2018) Imaging the young adult hip in the future. Ann Joint 3:47–47. doi: 10.21037/aoj.2018.04.10

53. Heyworth BE, Dolan MM, Nguyen JT, et al (2012) Preoperative Three-dimensional CT Predicts Intraoperative Findings in Hip Arthroscopy. Clin Orthop Relat Res 470:1950–1957. doi: 10.1007/s11999-012-2331-6

54. Mascarenhas VV, Rego PA, Dantas P, et al (2018) Hip shape is symmetric, non-dependent on limb dominance and gender-specific: implications for femoroacetabular impingement. A 3D CT analysis in asymptomatic subjects. Eur Radiol 28:1609–1624. doi: 10.1007/s00330-017-5072-9

55. Dudda M, Albers C, Mamisch TC, et al (2008) Do Normal Radiographs Exclude Asphericity of the Femoral Head-Neck Junction? Clin Orthop Relat Res 467:651–659. doi: 10.1007/s11999-008-0617-5

56. Saito M, Tsukada S, Yoshida K, et al (2016) Correlation of alpha angle between

various radiographic projections and radial magnetic resonance imaging for cam deformity in femoral head–neck junction. Knee Surg Sports Traumatol Arthrosc 1–7. doi: 10.1007/s00167-016-4046-9

57. Klenke FM, Hoffmann DB, Cross BJ, Siebenrock KA (2015) Validation of a standardized mapping system of the hip joint for radial MRA sequencing. Skeletal Radiol 44:339–343. doi: 10.1007/s00256-014-2026-z

58. Pfirrmann CWA, Mengiardi B, Dora C, et al (2006) Cam and Pincer Femoroacetabular Impingement: Characteristic MR Arthrographic Findings in 50 Patients. Radiology 240:778–785. doi: 10.1148/radiol.2403050767

59. Yoon LS, Palmer WE, Kassarjian A (2007) Evaluation of radial-sequence imaging in detecting acetabular labral tears at hip MR arthrography. Skeletal Radiol 36:1029–1033. doi: 10.1007/s00256-007-0363-x

60. Sutter R, Dietrich TJ, Zingg PO, Pfirrmann CWA (2015) Assessment of Femoral Antetorsion With MRI: Comparison of Oblique Measurements to Standard Transverse Measurements. AJR Am J Roentgenol 205:130–135. doi: 10.2214/AJR.14.13617

61. Lerch TD, Todorski IAS, Steppacher SD, et al (2017) Prevalence of Femoral and Acetabular Version Abnormalities in Patients With Symptomatic Hip Disease: A Controlled Study of 538 Hips. The American Journal of Sports Medicine 417:036354651772698. doi: 10.1016/j.cmpb.2007.02.010

62. Groh MM, Herrera J (2009) A comprehensive review of hip labral tears. Curr Rev Musculoskelet Med 2:105–117. doi: 10.1007/s12178-009-9052-9

63. Schmaranzer F, Todorski IAS, Lerch TD, et al (2017) Intra-articular Lesions: Imaging and Surgical Correlation. Semin Musculoskelet Radiol 21:487–506. doi: 10.1055/s-0037-1606133

64. Lee AJJ, Armour P, Thind D, et al (2015) The prevalence of acetabular labral tears and associated pathology in a young asymptomatic population. The Bone & Joint Journal 97-B:623–627. doi: 10.1302/0301-620X.97B5.35166

65. Tresch F, Dietrich TJ, Pfirrmann CWA, Sutter R (2016) Hip MRI: Prevalence of articular cartilage defects and labral tears in asymptomatic volunteers. A comparison with a matched population of patients with femoroacetabular impingement. J Magn Reson Imaging. doi: 10.1002/jmri.25565

66. Hanke MS, Steppacher SD, Anwander H, et al (2016) What MRI Findings Predict Failure 10 Years After Surgery for Femoroacetabular Impingement? Clin Orthop Relat Res 1–16. doi: 10.1007/s11999-016-5040-8

67. Lund B, Mygind-Klavsen B, Grønbech Nielsen T, et al (2017) Danish Hip Arthroscopy Registry (DHAR): the outcome of patients with femoroacetabular impingement (FAI). Journal of Hip Preservation Surgery 4:170–177. doi:

10.1007/s00167-008-0654-3

68. Nakano N, Gohal C, Duong A, et al (2018) Outcomes of cartilage repair techniques for chondral injury in the hip-a systematic review. International Orthopaedics (SICOT) 42:2309–2322. doi: 10.1007/s00264-018-3862-6

69. Zaltz I, Kelly BT, Larson CM, et al (2014) Surgical treatment of femoroacetabular impingement: what are the limits of hip arthroscopy? Arthroscopy 30:99–110. doi: 10.1016/j.arthro.2013.10.005

70. Hartigan DE, Perets I, Yuen LC, Domb BG (2017) Results of hip arthroscopy in patients with MRI diagnosis of subchondral cysts—a case series. Journal of Hip Preservation Surgery 4:324–331. doi: 10.1016/j.arth.2014.03.054

71. Krych AJ, King AH, Berardelli RL, et al (2016) Is Subchondral Acetabular Edema or Cystic Change on MRI a Contraindication for Hip Arthroscopy in Patients With Femoroacetabular Impingement? The American Journal of Sports Medicine 44:454–459. doi: 10.1177/0363546515612448

72. Krishnamoorthy VP, Beck EC, Kunze KN, et al (2019) Radiographic Prevalence of Sacroiliac Joint Abnormalities and Clinical Outcomes in Patients With Femoroacetabular Impingement Syndrome. Arthroscopy 35:2598–2605.e1. doi: 10.1016/j.arthro.2019.03.030